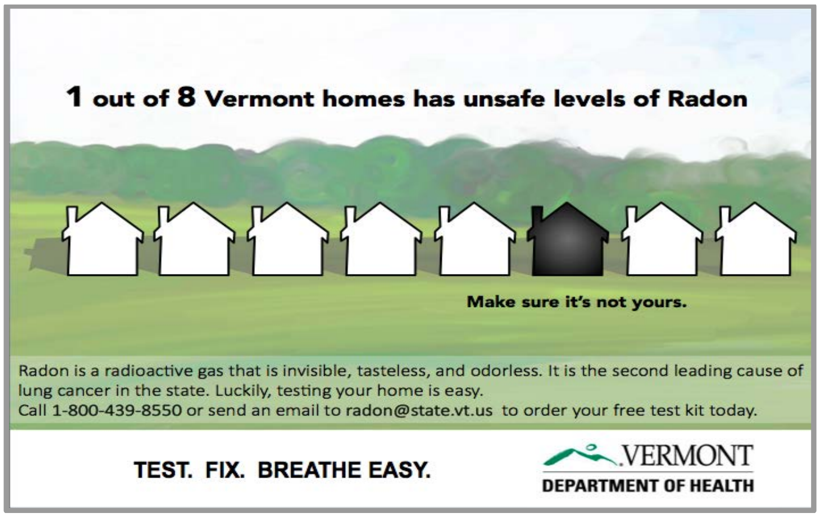
Radon Risk and Public Health in Vermont



Middlebury College
Environmental Studies Senior Seminar
Spring 2015

Led by:
Pete Ryan
Nick Muller
Diane Munroe

Community Partners:
Vermont Department of Health: David Grass
American Lung Association of the Northeast: Rebecca Ryan
Vermont Geological Survey: Jon Kim
Association of Vermont Radon Industry Professionals (AVRIP): Peter Crowley

Class Members
Assi Askala
Anna Breu
Katherine Eiseman
Scott Gilman
Chloe Horton
Rebecca Hicks
Julia John
Luis Fernando Sandoval Jimenez
Daniel Nigh
Mary Richards
Rebecca Roe
Dylan Sinnickson
Hayden Shea
Mei Jia Tan
Innocent Tswamuno
Natalie Valentin
Linda Waller
Lindsay Warne
Calvin Williams
Philip Williams
Kevin Wood

Table of Contents

Introduction

Radon is a naturally occurring radioactive gas that is released by bedrock in the process of uranium decay. In homes and buildings, radon can accumulate and result in an increased risk of lung cancer for inhabitants; radon is the second leading cause of lung cancer after smoking. The Environmental Protection Agency (EPA) determined 4 pCi/L and above to be the necessary action level for radon (National Research Council 1999). Investigating and mitigating radon as an environmental health risk was the focus of the seminal senior Environmental Studies course at Middlebury College; this project relied on a broad understanding of environmental studies and a connection to the community that it intended to serve. As part of this community connection, the class worked in close partnerships with the Vermont Geological Survey (VGS), the Vermont Department of Health (VDH), the American Lung Association (ALA), and the Association of Vermont Radon Industry Professionals (AVRIP). The investigation of radon risk in Vermont presented in this study has a four-pronged approach: a geospatial assessment of risk, a cost-benefit analysis of radon mitigation, the creation of a radon saliency program, and an informed policy brief.

The geospatial assessment locates areas of increased risk. A large portion of the analysis relies on the National Uranium Resource Evaluation (NURE) survey, and correlations between some types of NURE anomalies and existing radon test data indicate potential for NURE to be used to predict increased radon risk in Vermont. This task was designated by a partner at the VGS, who was independently working on a geospatial analysis comparing radon test data and geological risk factors such as bedrock material and soil type; pairing the analysis done by the VGS and the NURE survey analysis will create a thorough radon risk map of Vermont. The maps generated by this analysis are intended to inform policymakers and health official so they can most effectively distribute resources. However, the geospatial analysis does not take into account the cost effectiveness of mitigation.

To discern and quantify the effectiveness of radon mitigation, a thorough cost-benefit analysis was performed. It weighs the potential of lung cancer given the EPA's dose-response curve and the associated healthcare costs against the cost of mitigation, installation, and maintenance. The

analysis focused on two places of mitigation: schools and private homes. Also, it factors in smoking history, which has a synergistic effect with radon gas that increases the risk of lung cancer. The analysis found that mitigation is always beneficial in residential homes and schools, and that the greatest benefit:cost ratios come from mitigation of homes with the highest radon (Rn) concentrations or where smokers live.

Given the result of the cost benefit analysis, it is prudent to promote radon testing and mitigation, so a program to increase the salience of radon was developed. Since radon is tasteless, odorless, and colorless, the radon threat is not readily apparent. The goal of the program was to produce a series of radon-awareness messages. Research regarding the effectiveness of awareness campaigns guided the production of a three-pronged approach: targeted outreach materials, a relatable narrative, and an educational program. These materials are ready to be distributed in order to increase the awareness of radon throughout Vermont.

Finally, a policy brief was created that offers a matrix of options for a Vermont radon policy aimed at reducing the risk of radon exposure. For each policy goal, the matrix outlines the difficulty in passing the legislation, the financial commitment of the state, and the effectiveness of the policy at mitigating radon risk. An example of this is a testing policy in public buildings like schools, an approach that seems less difficult to pass as law or to manage than one in private homes. This analysis also indicates that a mandatory mitigation policy would be more difficult and more costly. The four policy recommendations in order of increasing cost are: an educational program, a real estate policy, a testing mandate, and a mitigation mandate. The purpose of the matrix is to help Vermont policymakers tailor a policy that can pass and be as effective as possible at mitigating risk.

The following sections of this report on geospatial analysis, the cost-benefit analysis, means by which VDH can raise saliency to motivate radon testing, and finally, the policy brief lay out a map of potential actions to help reduce radon risk in Vermont.

Chapter 1. Geospatial

Introduction

Radon is a naturally occurring gas that can concentrate indoors and cause lung cancer.[1] There are several factors that can influence the risk of radon exposure. This chapter includes a thorough review of potential sources of radon and the factors that influence radon concentration including: geology (bedrock factors), soil type, groundwater, architecture, and natural gas use. From this review, it is clear that bedrock, the initial source of radon, is the most important factor determining indoor radon concentration.

This chapter also examines spatial patterns of radon risk within Vermont. The review of radon factors informed the evaluation of spatial risk. Another aspect of the spatial analysis is the use of aerial National Uranium Resource Evaluation (NURE) data to assess if this nation-wide data set can be used to predict radon hotspots. These analyses will be important to risk calculation, which is vital for the formation of policy, public outreach, and the ability to prioritize the use of limited resources. Our final product is a map of radon risk potential as defined by NURE survey anomalies and population density that can serve as an informative tool for policy makers and public health officials.

Research

Pairing Residential Indoor Radon Tests with Aerial Radiometric NURE Data

In 1973, the Atomic Energy Commission (AEC)[2] initiated the National Uranium Resource Evaluation (NURE) program to identify uranium resources in the United States (Figure 1.1). The program included an airborne radiometric survey of the conterminous U.S. and Alaska to locate potential radioactive mineral deposits – the goal at the time was to evaluate the potential for uranium ore deposits. While based on aerial data, ground-based surveys and stream sediment surveys were also performed; both of these surveys found their own anomaly zones. The results of these surveys are useful to indoor radon analysis because equivalent uranium (eU) data provide an estimate of the surficial concentrations of radon parent materials (uranium, radium) in

[1] National Research Council, 1999
[2] In 1975 the AEC was replaced by the Nuclear Regulatory Commission (NRC) of the Department of Energy (DOE).

rocks and soils. Our group used GIS to pair these data with residential indoor radon test data from the Vermont Department of Health (VDH) to look for correlations between radioactive "hot spots" identified by the NURE surveys and incidences of high indoor radon contamination in homes. These data will be supplemented by geologic and soil maps developed by the VGS and VDH. If successful, we hope that this approach will be an inexpensive and replicable proxy to identify potential high-risk areas for exposure to radon gas.

Details on NURE Data

The NURE data are currently held by the U.S. Geological Survey (USGS) and are publicly available online.[3] The data were collected by aircraft on which a gamma-ray spectrometer was mounted. All areas were flown at about 400 feet above the ground, the optimum height for collecting radiometric data, and the line spacing varied from 3 to 6 mile intervals. A few selected quadrangles were flown at 1 to 2 mile spacing, and about forty smaller areas were flown at 0.25 to 1 mile spacing.

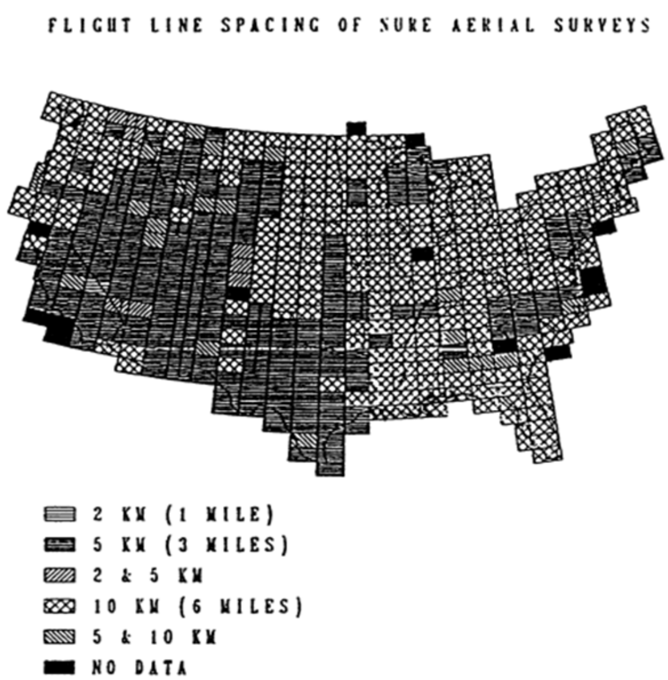


Figure 1.1: Flight line spacing of NURE aerial surveys from Hill et al. 2009

[3] Hill, Kucks, & Ravat, 2009

Some localized uranium anomalies may not have been detected by the aerial surveys; however, according to a 1993 USGS report, good correlations of eU patterns with geologic outcrop patterns indicate that, at relatively small scales (approximately 1:1,000,000 or smaller) the National eU map gives reasonably good estimates of average surface uranium concentrations and therefore can assist in the prediction of radon potential of rocks and soils, especially when augmented with additional geologic and soil data.[4] The NURE data used by our group is represented in Figure 1.2.

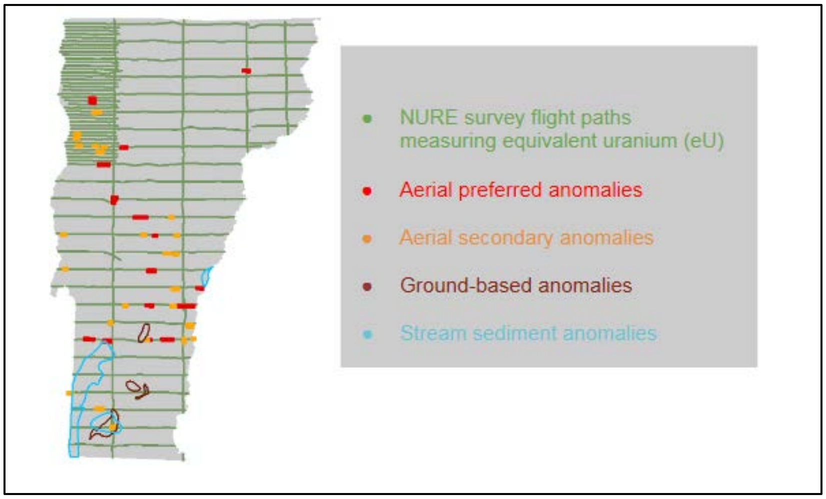


Figure 1.2: The NURE data used in our analysis included preferred and secondary anomalies from aerial surveys, ground-based survey anomalies, and stream sediment survey anomalies.

Previous Studies

We based our work on the methodology of two previous studies that have combined aerial radiometric data and in-home radon tests. Sheib et al. 2006 combined data on airborne uranium (eU) from planes, ground-based eU measured by in situ gamma spectrometry, indoor radon tests, and soil gas radon for Derbyshire, Central Britain.[5] The study found that airborne eU data correlate significantly (p=0.0005) with geometric mean indoor radon at the regional scale when using a 1-km grid square, where there are many indoor radon measurements, and when data are grouped by generalized geology.

[4] United States Geological Survey, 1993
[5] Scheib, Appleton, Jones, & Hodgkinson, 2006

In 1988, the New Jersey Geological Survey conducted a similar study as part of the New Jersey Statewide Scientific Study of Radon.[6] The researchers combined airborne NURE data with ground sampling and in-home radon testing and found that areas with airborne eU anomalies of 6 ppm or greater correlate well with homes where radon levels exceed 4 pCi/L. Of these homes, numerous had radon levels exceeding 200 pCi/L. It also found that 1/4 to 1/2-mile spaced aerial data are ideal for detecting clusters of homes elevated in radon and has shown an excellent correlation with radon testing results; 3-mile spacing can also be a good predictor, but requires greater input on underlying geology for accuracy; and the predictive power of the 6-mile spaced NURE data is limited. The study also emphasizes that house to house variations in radon within an area are dramatic.

Both studies affirm the importance of combining airborne radiometric data with underlying geologies. They also point to potential limitations in our study because many Vermont towns have less than 10 indoor radon measurements, and NURE survey flights paths were generally 6 miles (10 km) apart. Finally, they emphasize that these kinds of risk potential maps do NOT accurately predict radon contamination on a house-by-house basis because house structure and weather conditions play an important role.

Architecture, House Structure, and Demographics

High indoor radon levels may be attributable to the architecture and structure of the building, as well as the demographics of the inhabitants. The geographic location of the house has a direct influence on indoor radon levels due to underlying geology. Seasonal variability strongly influences radon levels as a result of the pressure differentials within the house that result from heating systems.[7] In addition, houses in rural environments have been found to have higher radon levels than those in suburban environments and those in urban environments.[8,9]

One important architectural feature that should be considered when looking at radon levels is the age of the building. While one article has found that there is a slightly positive relationship between radon and age,[10] another study found that houses that are 90 years or older (n = 725) tended to have the highest radon levels overall, and that houses 40 years or younger (n = 3,957)

[6] Muessig, 1998
[7] Cohen & Gromicko, 1988
[8] Cohen & Gromicko, 1988
[9] Cohen, 1991
[10] Karpinska, Mnich, Kapala, & Szpak, 2009

had higher radon levels than the middle-range houses that were 41-90 years old (n = 966).[11] In houses that have been built more recently, those built at higher costs have been found to have higher levels of radon than those built at lower costs. However, this trend is reversed in older houses, where low-cost houses have higher radon levels than more expensively built houses.[12] In general, the houses that are most at risk for high radon levels are older houses in rural areas with unfinished or partially finished basements.[13] As of the year 2000, approximately 41.3% (121,685) of homes in Vermont were built in 1959 or prior; 58.7% (172,686) of homes in Vermont were built in 1960 or later.[14]

The quality of the house and the socio-economic status (SES) of its inhabitants have also been found to have an impact on indoor radon concentrations. In low-cost houses occupied by low-income families, weatherizing was found to increase radon levels (15-20%), while the opposite effect is observed in expensive houses occupied by high-income families. One possible explanation that Cohen (1991) provides for this trend is that the mitigation available to those of low-income may include sealing cracks in the foundation of their homes which inhibits air exchange and the opportunity for radon to be exchanged with the outdoor environment. In contrast, those of higher-income may have access to better weatherization techniques that do not affect airflow, such as insulation.[15]

Multiple studies have concluded that the structural characteristics and construction materials of houses may be correlated with indoor radon contamination. Single-family houses were found to have higher radon levels than blocks of flats, although this finding may be a result of the types of materials used to construct these buildings.[16] Houses with wood exteriors were found to have substantially higher radon levels than those constructed with brick or stone. Although there is no definite explanation for this correlation, it could be explained by a tendency for wood houses to be more tightly sealed or the combined result of the types of houses and the construction materials used in specific geographic and geologic areas.[17]

Overall, despite some of the correlations that have been determined between radon levels and these types of architectural and demographic factors, such as location, house age, construction

[11] Rugg, 1988
[12] Cohen & Gromicko, 1988
[13] Shendell & Carr, 2013
[14] US Census Bureau, Census 2000 Summary File 3
[15] Cohen, 1991
[16] Karpinska, Mnich, Kapala, & Szpak, 2009
[17] Cohen, 1986

materials, structure quality, and SES of the inhabitants, geologic factors have been found to be a much better indicator of radon levels.[18]

Geology of Radon

To understand the geology of radon—where it forms, how it forms, how it moves—we have to start with its initial source, uranium. All rocks contain some traces of uranium, although most contain a small amount—between 1 and 3 parts per million. Light colored volcanic rocks, granites, dark shales, sedimentary rocks containing phosphate, and metamorphic rocks may contain as much as 100 ppm uranium. The higher the uranium level is in an area, the greater the chances are that houses in the area have high levels of indoor radon.[19] Radon gas has a much greater mobility than uranium and radium, which are much more likely to remain fixed in rocks and in the solid matter in soils. Radon can easily diffuse through rocks and soils by escaping via fractures and openings in rocks and into the pore spaces between grains of soil.[20] Radon travels shorter distances in wet soils than dry ones before it decays. For these reasons, homes in areas with drier soils and bedrock, such as hillslopes, mouths and bottoms of canyons, coarse glacial deposits, and fractured or cavernous bedrock, may have high levels of indoor radon.[21]

Radon can diffuse into water from bedrock. The highest concentrations of radon in groundwater are associated with proximity to uranium-rich bedrock, uranium-rich mineral deposits, and fracture zones.[22] The natural process of uranium decay releases radon, which can dissolve into the water. However, one study found that the levels of radon in groundwater samples were proportionally higher than the parent materials of uranium and thorium. This led to the conclusion that radon can diffuse directly from bedrock; it does not only come from aqueous uranium decay.[23] Although radon-rich groundwater can be pumped into homes through well systems and contribute to indoor radon gas, the rate of evaporation is 1/10000 pCi/L, so a water sample with 1000 pCi/L would increase indoor radon levels by 0.1 pCi/L.[24] This means that well

[18] Cohen, 1991
[19] Vincente E. Guiseppe, 2006
[20] Otton, 1992
[21] O'Brien, Risk, Rainham, & O'Beirne-Ryan, 2014
[22] Choubey & Ramola, 1997, Akerblom & Lindgren, 1997, Vinson, Vengosh, Hirschfeld, & Dwyer, 2009, Skeppstrom & Olofson, 2006
[23] Wanty, Johnson, & Briggs, 1991
[24] Cothern, 1990, Hopke et al., 2000

water with dissolved radon does not significantly contribute to indoor radon except in extreme cases, but it can nonetheless be a proxy for it.

Levels of radon decrease exponentially with greater soil depth. An increase in the moisture content of soil leads to a decrease in the diffusion coefficient of radon. Porosity also plays a critical role in radon emanation as diffusion increases with an increase in porosity.[25] Soils with low permeability like clays are able to contain radon within the soil as the gas cannot readily diffuse through the pore space.[26] Porous soils provide radon pathways to move into homes. It is important to note that if soils have high porosity but the pores are filled with water, then diffusion will be low due to the moisture content.

Radon and Natural Gas

In addition to water, natural gas for domestic use is another pathway for radon to get into homes. Because radon is an inert gas, it is unaffected by combustion. A 1973 EPA study found that radon induced lung cancer from radon coming into homes with natural gas was responsible for 15 deaths per year, and recommended against mitigation due to the high costs. [27] With the increased production and consumption of natural gas in the U.S. in the past decade this issue should be revisited. This is particularly important in light of the fact that most of the increased production is coming from radon-rich shale formations.

A study on radiation exposure from oil and gas development by the Pennsylvania Department for Environmental Protection (DEP) concludes that there is no increased risk of radon exposure in homes burning natural gas.[28] However, the DEP bases its findings on a model that assumes 68% air exchange with the outdoors every hour, which is a high estimate, particularly for homes in cold areas.

The natural gas coming to Vermont through the VT Gas pipeline is connected to the Trans-Canada pipeline network (Figure 1.3), and the gas coming to Vermont will be extracted in western Alberta. Because of radon's short half-life (3.8 days), the levels of radon in the natural gas will have dramatically dropped by the time it gets to Vermont homes.

[25] Shweikani, Giaddui, & Durrani, 1995
[26] Schumann & Gundersen, 1996
[27] Johnson Jr, Bernhardt, Nelson, & Calley Jr, 1973
[28] Pennsylvania Department of Environmental Protection, 2015

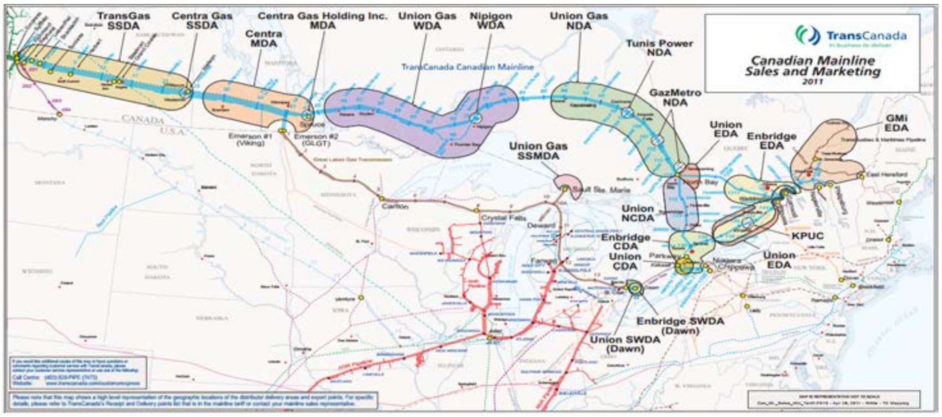


Figure 1.3: Trans-Canada pipeline network showing that natural gas for the VT Gas Pipeline is coming from western Alberta, where there is uranium-rich shale.

However, empirical studies are necessary before drawing a final conclusion. The existing literature shows that science has paid little attention to this issue. It is also important to look into the risk of exposure to radon progeny accumulated in pipes and released into homes.

Discussion

Of the 11,000 home radon tests coded to a physical address in our data set, provided by the VDH, we found that approximately 1 out of 8 homes in Vermont has elevated radon, defined as at or above the EPA action level of 4 pCi/L (see Table 1.1, Figures 1.4 and 1.5).

Table 1.1: Results of home radon test kits in Vermont split at the EPA action level (4 pCi/L) and the general mitigation level (2 pCi/L).

Test Range (pCi/L)	Number of Tests	Percentage
< 2	8335	71.2%
≥ 2 and < 4	1961	16.7%
≥ 4	1418	12.1%

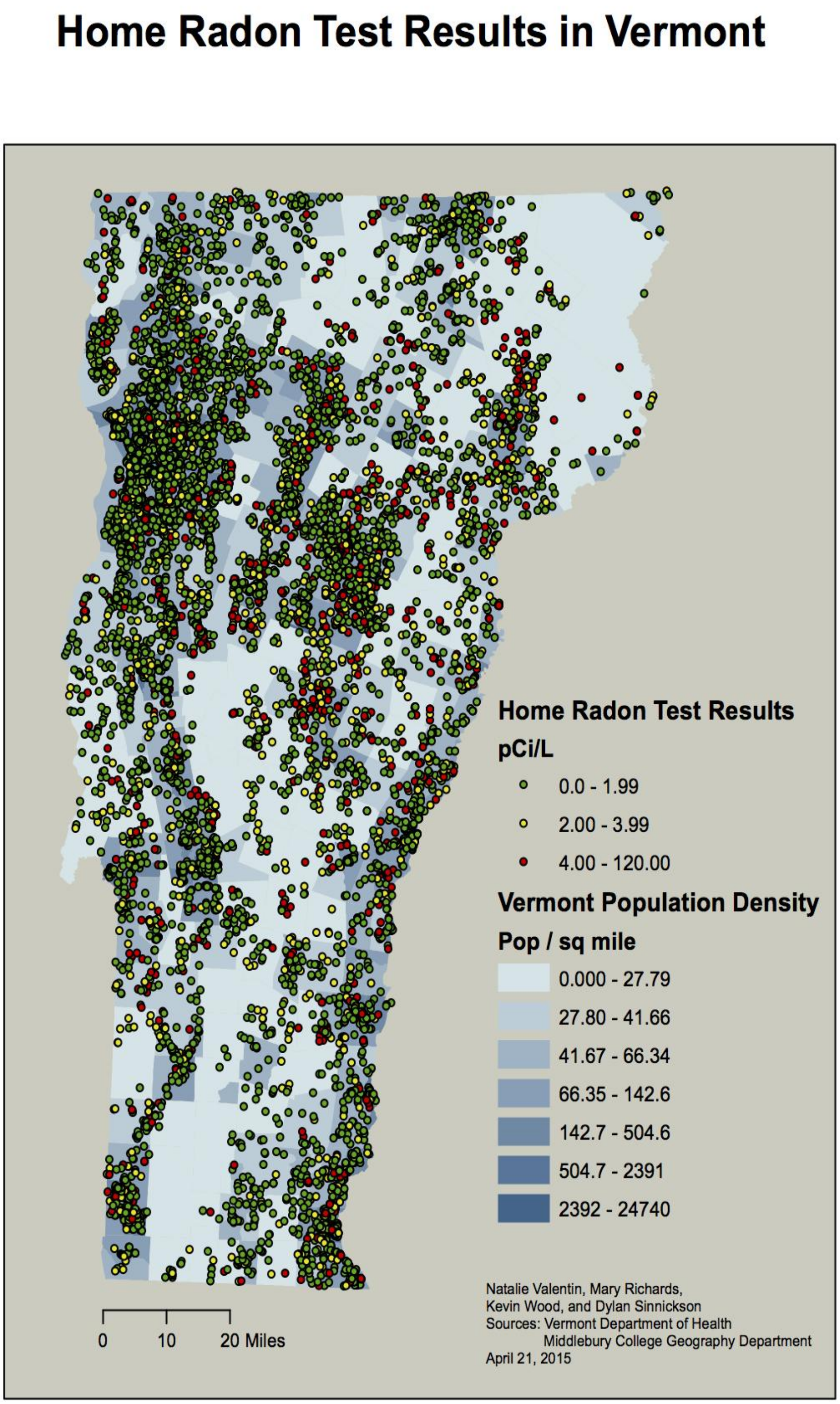


Figure 1.4: Distribution of all home radon tests coded to a physical address in Vermont, overlaid on population density by census tract. See Appendix A for metadata.

Home Radon Test Results Above 4 pCi/L in Vermont

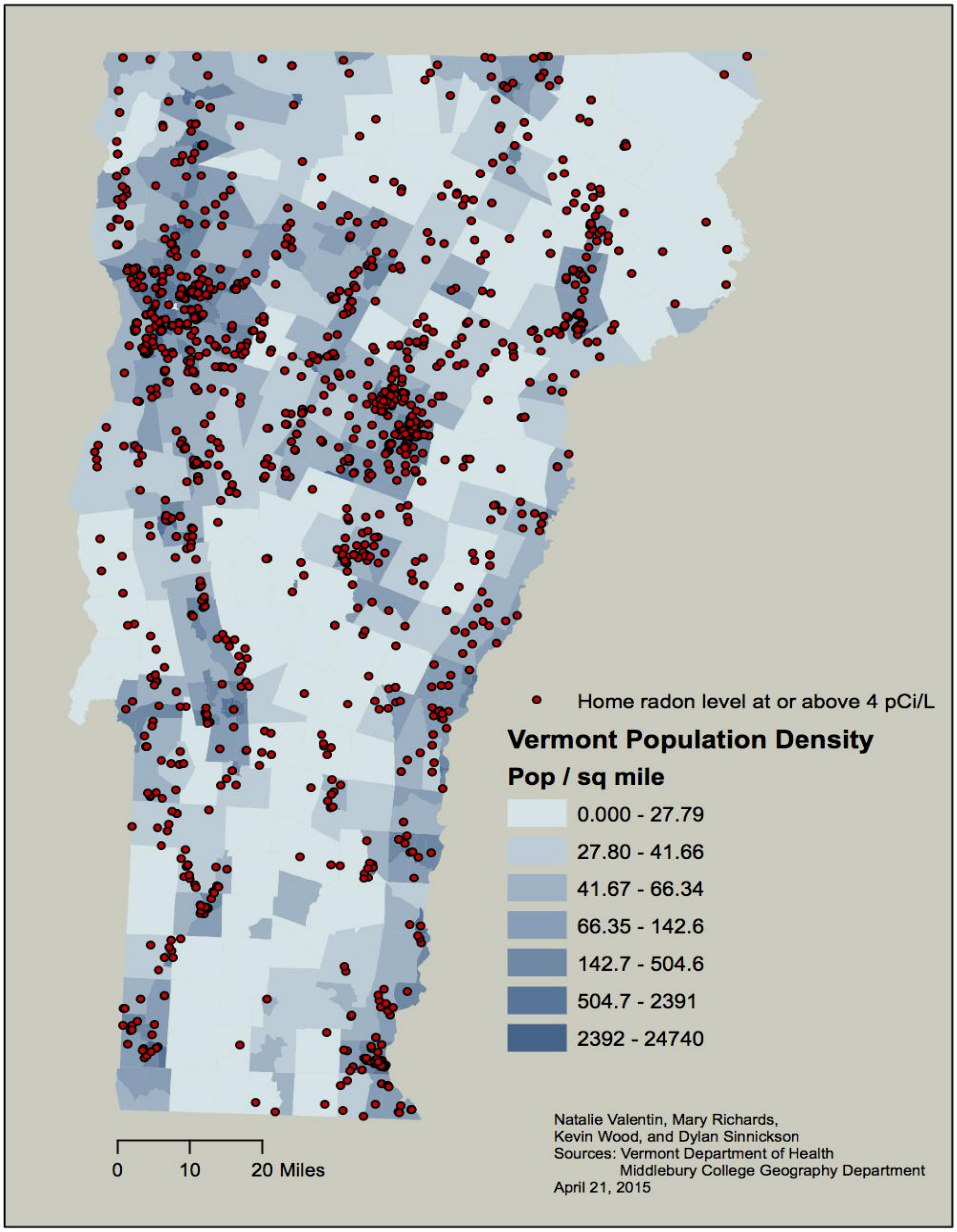


Figure 1.5: Distribution of home radon tests exceeding the EPA action level in Vermont, overlaid on population density by census tract. See Appendix A for metadata.

We found that there is a statistically significant correlation between NURE aerial and stream sediment anomalies and increased levels of radon in homes. We found that within these anomaly areas, there are a greater proportion of homes with tests above 4 pCi/L than outside of the anomaly areas.

NURE Aerial Anomalies

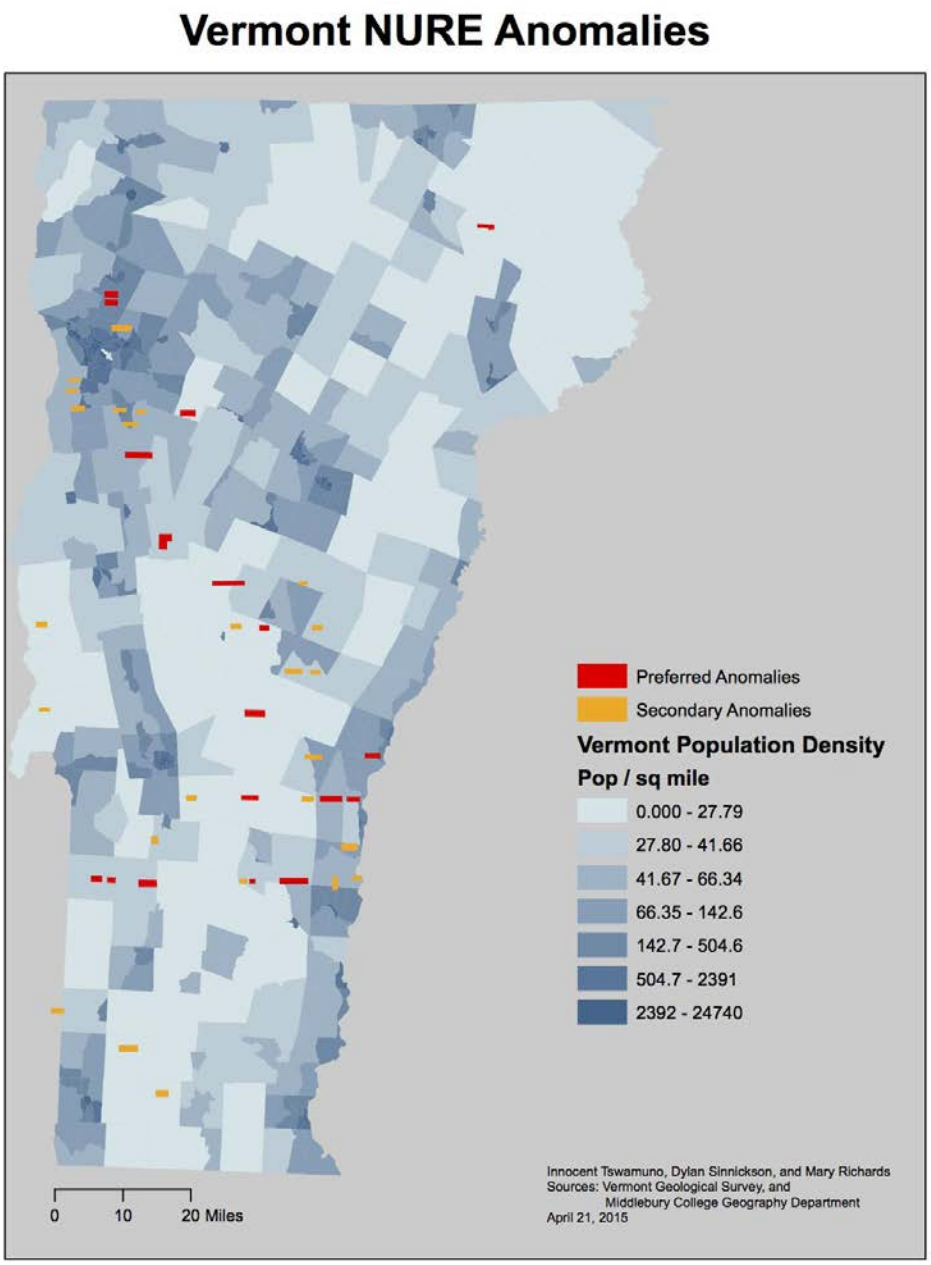


Figure 1.6: Distribution of primary and secondary anomalies identified by the NURE aerial radiometric survey data. 75 home radon tests fall within the 18 preferred anomalies, and 65 home radon tests fall within the 25 secondary anomalies. See Appendix A for metadata.

Within the preferred anomalies, the proportion of homes testing at or above the EPA action level was double the proportion outside any aerial anomalies. Within the secondary anomalies, the proportion of homes testing at or above the EPA action level was just under double the proportion outside any aerial anomalies (Tables 1.2-1.4).

Table 1.2: Home radon test results that fall within the preferred anomalies from the aerial NURE survey.

Test Range (pCi/L)	Number of Tests	Percentage
< 2	50	66.6%
≥ 2; < 4	6	8%
≥ 4	19	**25.3%**

Table 1.3: Home radon test results that fall within the secondary anomalies from the aerial NURE survey.

Test Range (pCi/L)	Number of Tests	Percentage
< 2	42	64.6%
≥ 2; < 4	9	13.8%
≥ 4	14	**21.5%**

Table 1.4: Home radon test results that do not fall within either preferred or secondary anomalies. It serves as the control group.

Test Range (pCi/L)	Number of Tests	Percentage
< 2	8243	71.2%
≥ 2; < 4	1946	16.8%
≥ 4	1385	**12%**

The difference between the proportion of tests within each of the three testing categories inside the aerial anomalies and outside of the aerial anomalies is statistically significant (Figure 1.7 and Figure 1.8). For preferred anomalies, secondary anomalies and both combined, homes within these areas had a greater proportion of tests at or above the EPA action level, as well as a lower proportion of tests below 2 pCi/L.

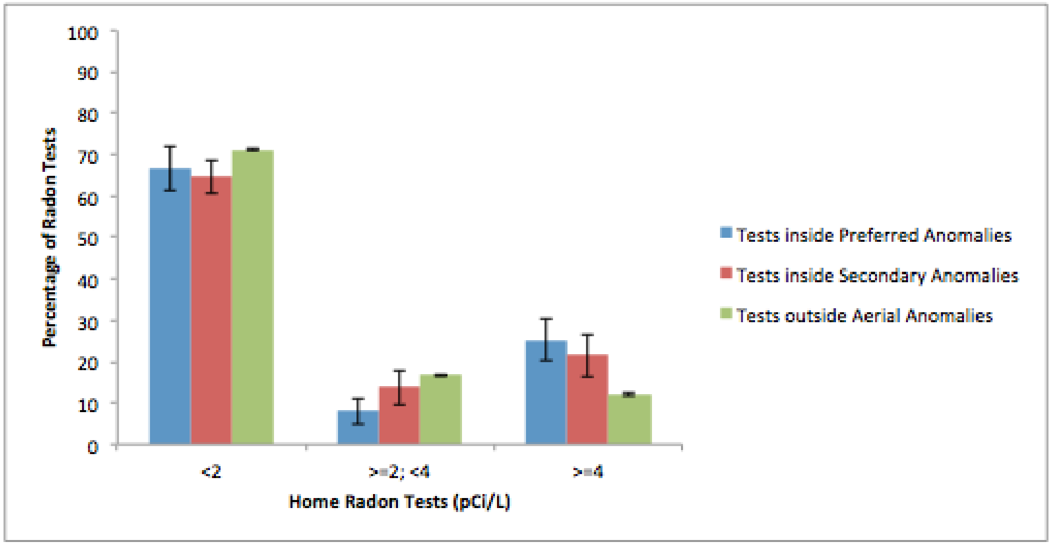


Figure 1.7: Proportion of home radon tests below 2 pCi/L, between 2 and 4 pCi/L, and equal to and above 4 pCi/L inside NURE aerial survey preferred anomalies, inside NURE aerial survey secondary anomalies, and outside these anomalies.

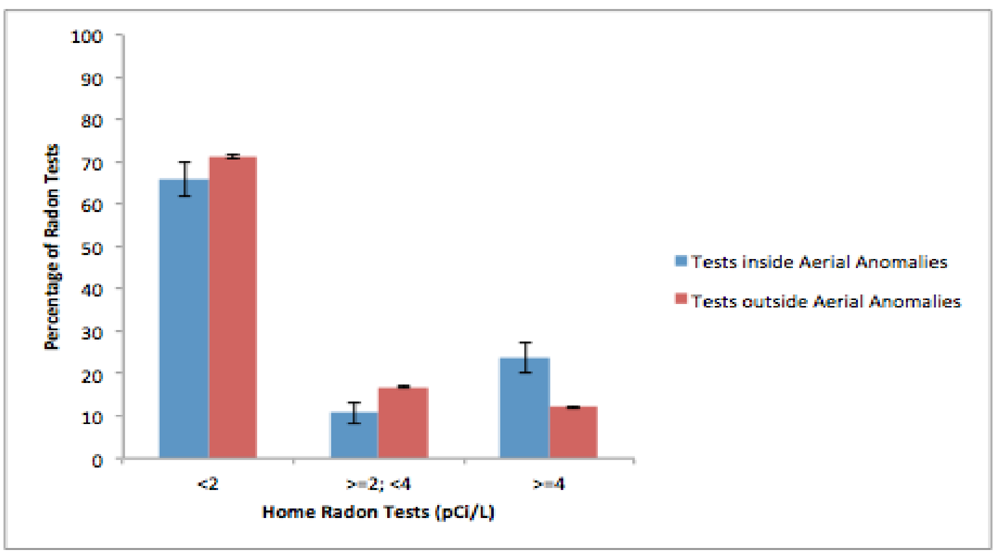


Figure 1.8: Proportion of home radon tests below 2 pCi/L, between 2 and 4 pCi/L, and equal to and above 4 pCi/L inside NURE aerial survey anomalies, which is a combination of preferred and secondary anomalies, and outside aerial anomalies.

NURE Stream Sediment Anomalies

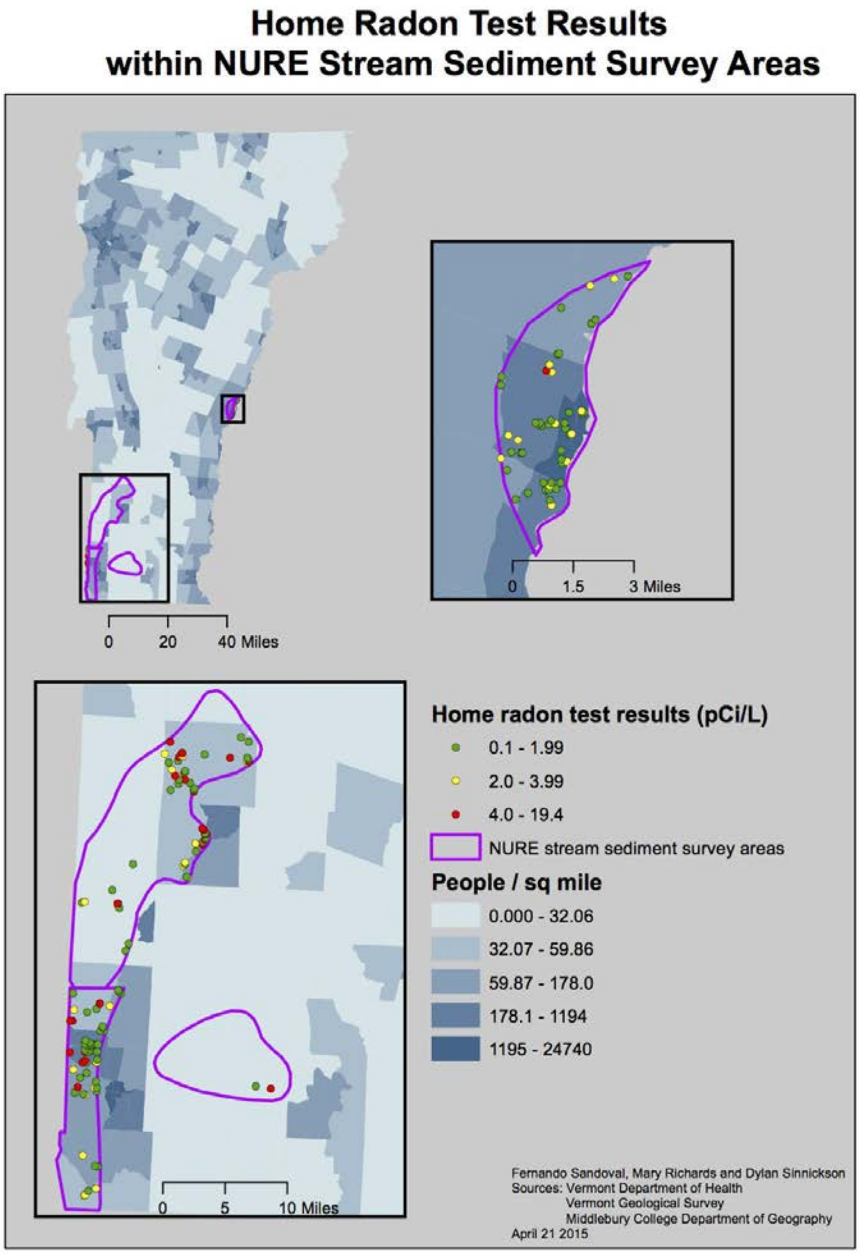


Figure 1.9: Uranium-rich zones delineated by the NURE survey of stream sediment overlaid onto a map of Vermont population density by census tract. The point data show the home radon tests that fell within these zones. Of all of the indoor home radon tests, only 1.5% (177 of 11537) fell within the high uranium stream sediment polygons. See Appendix A for metadata.

Of all of the indoor home radon tests, only 1.5% (177 of 11537) fell within the high uranium stream sediment polygons. Within this subset of home radon tests that fell within the stream sediment anomalies, the frequency of higher indoor radon readings is greater than in the rest of Vermont; 62% of homes in high uranium areas have a low indoor radon reading of <2 pCi/L, compared to 71% of homes outside of these areas; 23% of homes in the stream sediment polygons have a moderate reading of 2-4 pCi/L per liter, compared to 17% of homes elsewhere; and 16% of homes in the stream sediment polygons have a high reading of 4 or more pCi/L, compared to 12% of homes elsewhere (Table 1.5).

Table 1.5: Home radon test results that fall within the stream sediment anomalies from the NURE survey compared to the statewide data.

Test Range (pCi/L)	**Tests results within stream sediment anomalies (%)**	**Test results statewide (%)**
< 2	61.6	71.3
≥ 2; < 4	22.6	16.7
≥ 4	**15.8**	**12.0**

Overall, the results indicate elevated radon levels within NURE anomalies in comparison to areas outside of the NURE anomalies. Using a z-test, the there was a significantly greater number of home radon tests (HRTs) above 4 pCi/L inside the stream sediment anomalies in comparison to those outside of the anomalies ($p < 0.001$). There was a significantly greater number of HRTs found above 4pCi/L inside the preferred anomalies ($p < 0.001$) and inside the secondary anomalies ($p < 0.05$) than those found outside of the anomalies (Figure 1.10).

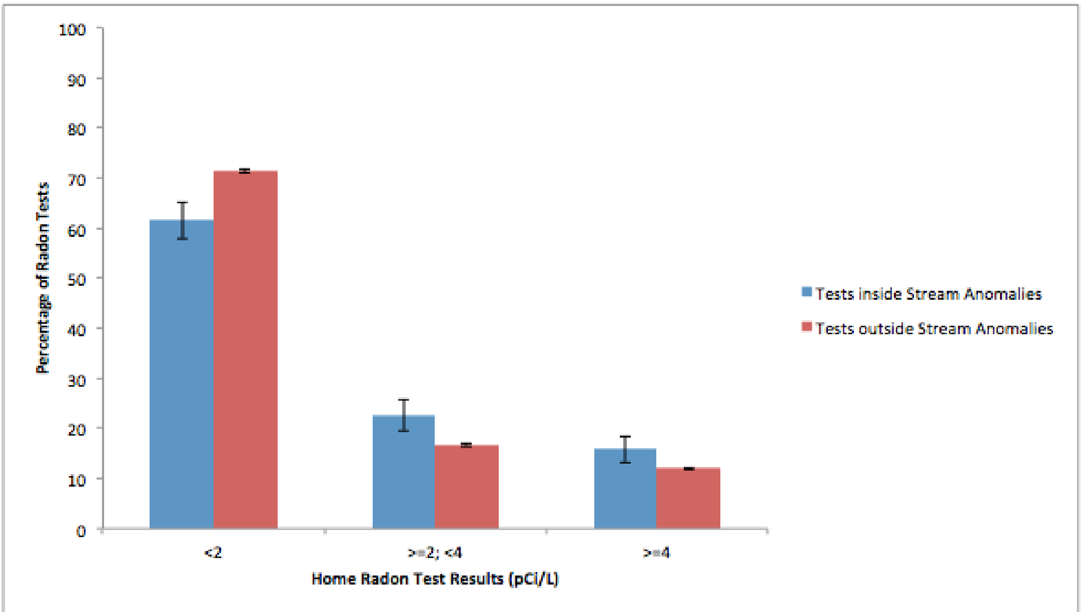


Figure 1.10: Proportion of home radon tests below 2 pCi/L, between 2 and 4 pCi/L, and equal to and above 4 pCi/L inside NURE stream survey anomalies and outside these anomalies.

Ground-based Surveys

Only 3 home radon tests overlapped with ground-based surveys, so we were unable to draw any conclusions from the data (Figure 1.11).

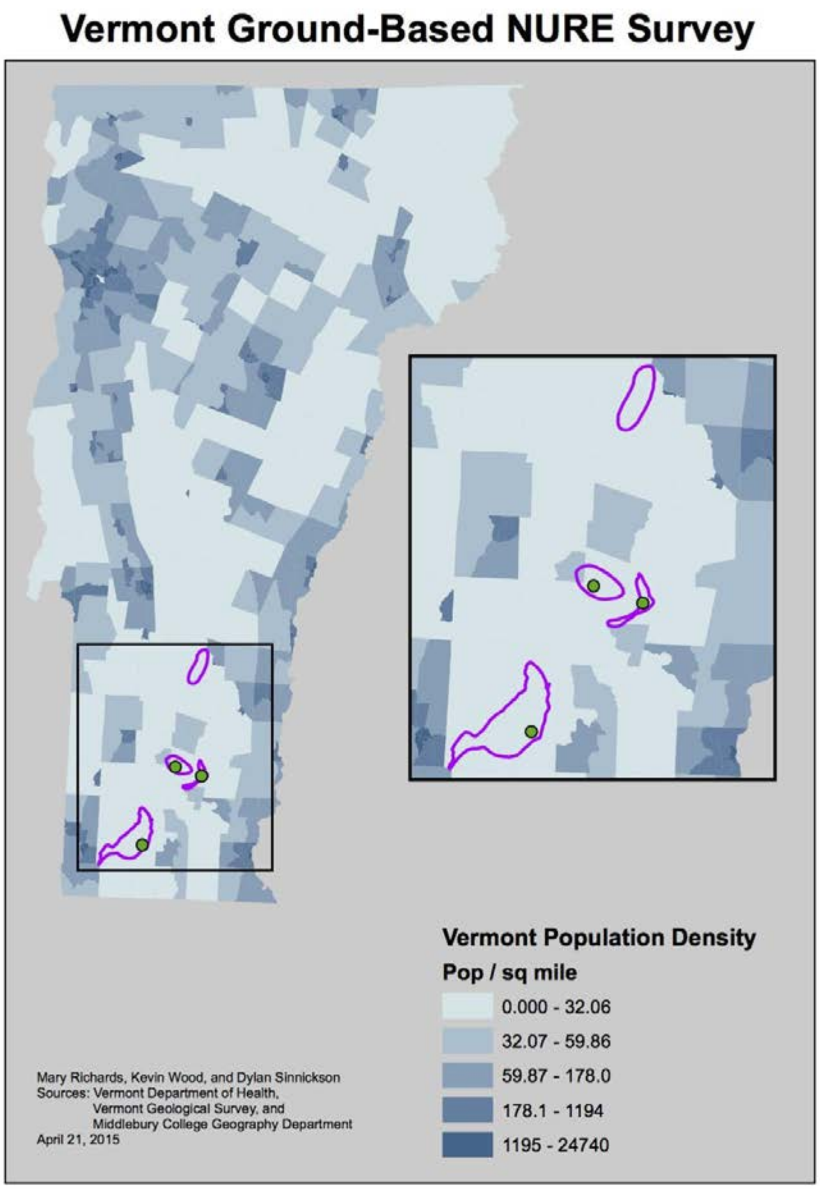


Figure 1.11: This map features the uranium-rich zones delineated by the ground-based NURE survey overlaid onto a map of Vermont population density by census tract. The uranium-rich zones are in low-population areas. As a result, only three home radon tests fell within these areas. See Appendix A for metadata.

Identifying Priority Areas

The maps below show the location of aerial and stream sediment anomalies overlaid with population density and overall population (Figure 1.12). These maps can be used for strategic planning for policymakers, allowing them to make informed decisions regarding the prioritization of resources and targeted outreach campaigns.

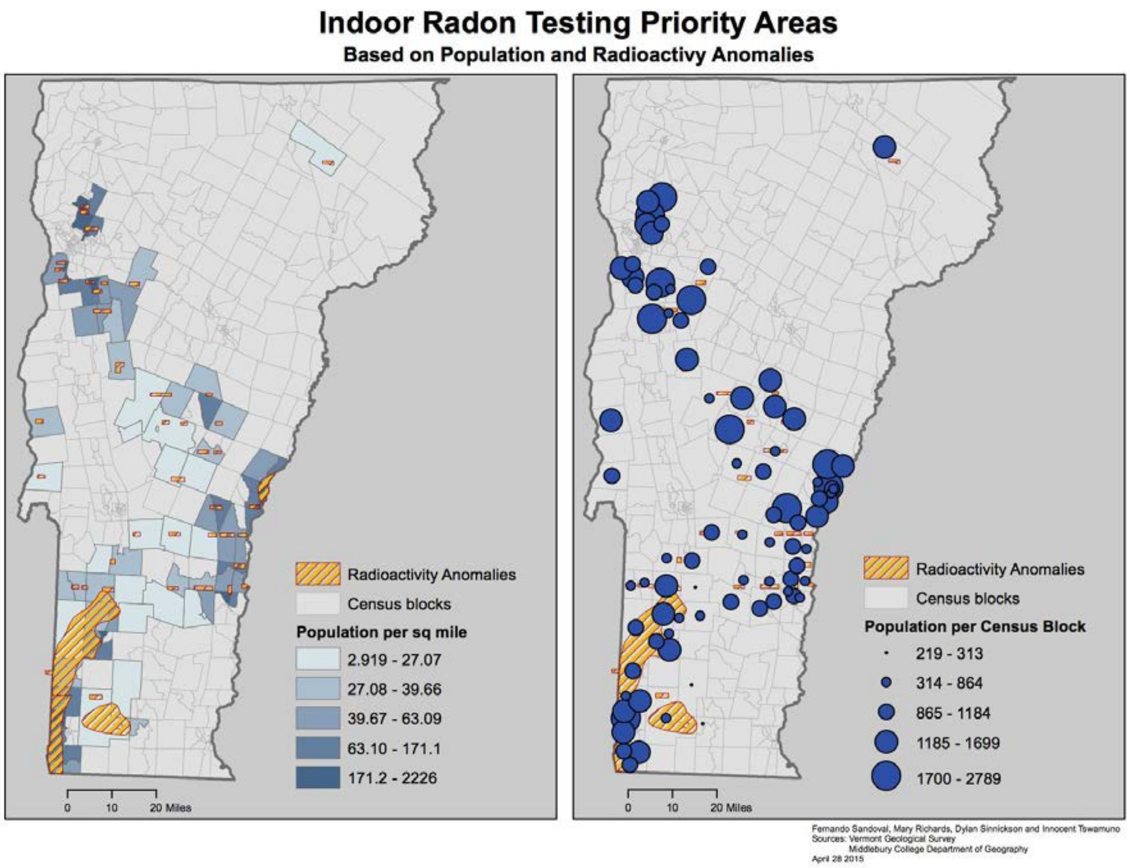


Figure 1.12: These maps highlight areas where testing for indoor radon should be made a priority based on population and NURE radioactivity anomalies (combination of stream sediment anomalies and airborne preferred and secondary anomalies). Both maps illustrate the counties in which NURE anomalies were found, with the map to the left showing the population density within each census block of concern and the map to the left showing the population of each census block. See Appendix A for metadata.

Our results are also promising because they confirm the results of previous research using a similar methodology.[29] This means that other states can use NURE surveys as guidelines for their own radon programs.

[29] Muessig, 1998

Conclusion

There is significant evidence indicating that underlying bedrock is likely the most significant factor affecting indoor radon levels. Homes located on permeable, dry soils and fractured uranium rich bedrock are generally at greater risk for elevated levels of radon. NURE surveys may be a valuable tool to assess radon potential—our analysis of both localized anomalies and stream sediment surveys demonstrates a relationship between elevated radioactivity and elevated radon levels for these specified areas; however, our study reveals no relationship between airborne radioactivity and home radon levels for the state as a whole. These somewhat conflicting results could suggest the importance of other contributing factors such as architecture, groundwater characteristics, and natural gas use affecting radon levels in the state as well.

While our results do reveal radon hotspots in the documented anomalies and areas with elevated uranium in stream sediment, the findings should be interpreted with some caution. These hotspots are by no means the only locations where there are elevated radon levels in homes, but instead, areas that are potentially at greater risk. Radon exposure is a problem throughout Vermont and testing should be encouraged statewide. These maps merely provide insight regarding where it would be ideal to focus salience efforts and legislation when dealing with radon. Lastly, it is important to account for the varying population densities in Vermont, as citizens are not equitably distributed throughout the state. Allocating resources to areas with a high population and proximity to a primary anomaly would be most effective.

Chapter 2. Cost-Benefit Analysis of Radon Mitigation in the State of Vermont

Introduction

Risk is associated with any environmental toxin. In the case of radon, risk is defined as the chance of death due to radon-induced lung cancer (EPA 2003b). Once radon is detected in a structure, this risk can only be reduced through radon mitigation. The overall purpose of the project presented in Chapter 2 was to conduct a cost-benefit analysis of radon mitigation in the state of Vermont. This analysis was applied to both households and schools in Vermont. The results of our analysis are meant to inform both homeowners and policy makers as they outline statewide policy.

Radon mitigation technology does come with a substantial monetary cost. While there are a variety of mitigation technologies, the most common method employed in the state of Vermont is sub-slab suction. Mitigators run a pipe from beneath the foundation of the house, with the goal of depressurizing the soil beneath the home relative to the indoor air. A fan, at the apex of the pipe system, draws air out of the ground and releases it above the home (Henschel 1994). Consequently, there is less radon working its way through the foundation and contaminating the home. Mitigators routinely pair sub-slab suction with caulk sealing of the structure's foundation, as a tighter foundation is effective in reducing indoor radon levels (Henschel 1994; Peter Crowley personal communication, March 12, 2015). The installation (of the sub-slab suction) and the operation and maintenance (of the fan) comprise the private costs of radon mitigation.

We classify benefits obtained from mitigation as the reduction of risk resulting from the reduction of radon concentration within the home. Assuming a linear dose-response relationship (EPA 2003b), risk reduction—the change in the probability of mortality from radon-induced lung cancer—can be calculated per pCi/L of radon reduced. We convert this risk reduction into monetary terms using the value of a statistical life year (VSLY) calculated by the EPA, for the purpose of comparing costs and benefits (Dockins et al. 2004).

We then constructed a model that allowed us to compare costs and benefits for any structure with radon levels above the 4 pCi/L action level defined by the EPA. In addition to this model, we have researched the benefits of radon mitigation to the health care system and the

socioeconomic implications of radon mitigation in Vermont. We have also included a discussion of exported risk as a result of air pollution due to the energy demand of sub-slab suction fans. Through the monetization of risk reduction, we hope to provide decision makers with numbers that can help to inform the distribution of a limited budget. We hope that our analysis can inform radon mitigation policy and support decision-making around the allocation of funds.

Methodology

Methods

Our analysis considered several different scenarios (ranges of baseline radon concentrations) and sought to represent the costs and benefits of mitigation across three scales: in homes, schools and within the Vermont health care system. To compare the cost of mitigation (dollars) and the benefit accrued with mitigation (change in risk as a result of pCi/L of radon reduced), we collected and analyzed data from two sources: the Vermont Department of Health (VDH) and Peter Crowley, a radon mitigation professional here in Vermont. For the sake of comparison, we then monetized the benefit of risk reduction by introducing the Value of a Statistical Life Year (VSLY). Finally, we examined the same costs and benefits of radon mitigation for smokers, as smoking has been suggested to have positive synergistic effect on the risk of mortality from radon-induced lung cancer.

Data Collection

We collected and summarized VDH's annually administered radon mitigation questionnaires to understand the mitigation that is already in place in the state of Vermont. For the purposes of our analysis, we were interested in questions of who is mitigating, at what radon concentrations and with what mitigation technology. The questionnaires are distributed to those who requested a VDH radon test kit. On mitigation questionnaires, participants are asked to provide information on the cost of mitigation, pre- and post-reduction radon concentrations and the types of mitigation technology used in their home. In 161 responses over three years (between 2012 and 2014), Vermonters indicated sub-slab suction as the primary mitigation technology. On average, these systems cost Vermonters $1,000-2,000 for the initial installation. Pre-mitigation radon levels varied tremendously with a lower extent of 4 pCi/L and an upper extent of 71 pCi/L.

Although useful, the questionnaire data did not provide a large enough sample of radon levels in Vermont homes to calculate an average cost per picocurie reduced. We augmented these data with data from VDH's statewide testing program. In this program approximately 20,000 buildings have been tested for radon concentration and, of those 20,000, approximately 11,000 have been geocoded to a physical address. A test does not necessarily indicate mitigation, therefore only the initial radon concentration is reported. From these data we developed three radon level scenarios for buildings with radon above the 4 pCi/L action level: low radon (4 to 10 pCi/L), moderate radon (10 to 30 pCi/L) and high radon levels (greater than 30 pCi/L), found in Vermont homes. We determined these low, moderate and high scenarios based on the frequency distribution of testing data: 80% of the testing data fell in the low radon range, 19% fell in the moderate range, and 1% in the high range. Our groupings of radon scenarios may seem arbitrary, but we created them intentionally to represent the diversity of radon exposure within the state while also recognizing that most Vermonters are exposed to radon levels below 10 pCi/L. We included the high radon exposure in the analysis, even though it is only present in 1% of Vermont houses, because individuals in houses with extremely high pre-mitigation radon levels are particularly at risk of developing radon-induced lung cancer. We felt it was important to understand how people in high-risk radon scenarios do or do not experience benefits from mitigation.

We used Peter Crowley's records of mitigation technology installations to better understand cost. Peter Crowley is a National Environmental Health Association and National Radon Proficiency Program certified radon mitigation professional. According to his data, the median cost of a mitigation system for one of his clients is $1,800 (N = 131). Various cost-benefit and cost-efficiency studies analyzing radon abatement corroborate this component of our model (Petersen and Larsen 2006; U.S. Environmental Protection Agency 2003). We used Peter's dataset to represent the cost of installation for mitigation systems because each data point is a specific cost, rather than the range represented in VDH's Mitigation Surveys and therefore offers increased accuracy.

Sub-slab suction units do not only require one upfront investment, but also a monthly payment for the electricity necessary to operate the fan. To understand the cost of running a mitigation system in Vermont, we multiplied the cost of a kilowatt hour of electricity in Vermont ($0.15) by the amount of energy that the most common radon fan uses per year—473 kWh

(Green Mountain Power 2015; RadonAway 2012). According to Peter Crowley, the fans last at least 20 years (Peter Crowley, personal communication), before they need to be replaced. We therefore calculated the cost of running the system twenty four hours a day, 7 days a week for 20 years, or $70.96 per year based on the most popular fan, the RP145, provided by the largest radon technology company, RadonAway (RadonAway 2012). Using similar calculations, the average Vermont school would face a $354.80 per year operation cost, given that the average school uses five fans (Peter Crowley, personal communication). We were also interested in understanding how mitigation units' additional electricity pull contributes to air pollution generation within the New England Power Grid, the Northeast Power Coordinating Council (NPPC). We calculated the amount of gross external damages (GED) generated by these units and added the cost, $2.62, of generating that air pollution onto the yearly operating costs of the fan units according to methodology in Muller et al. (2011).

To understand the benefits accrued via mitigation, we used the dose-response relationship for radon exposure (United States Environmental Protection Agency 2003; Figure 2.1) to estimate the change in mortality risk, given pre-mitigation radon concentration and post-mitigation radon concentration. The dose-response curve implies a linear relationship between radon exposure level and risk of mortality for radon-induced lung cancer. There are three distinct relationships – a relationship for smokers, a relationship for never-smokers and a relationship for the general public. With the pre- and post-mitigation concentrations and one of the three curves, we calculated the reduction of risk. We multiplied the reduction of risk across the entire exposed population within a given structure.

We also examined the nature of mitigation for schools in Vermont. We procured our data concerning schools from VDH, the Vermont Department of Education's website and information from Peter Crowley's work with schools in Vermont. For schools we collected similar data as for private households. We determined the initial cost of installing mitigation technology (schools also use sub-slab suction), calculated operation and maintenance costs in the same way as for private households and used the same testing data to establish radon levels within schools. A summary of the data we collected for private households and for schools in this section can be found in Table 2.1.

For the sake of comparison, we placed a monetary value on the change in risk. Although we realize that the value of a statistical life as determined by the EPA is controversial, it is an

established method of comparing the benefits of risk reduction to the costs of mitigation (Dockins et al. 2004).

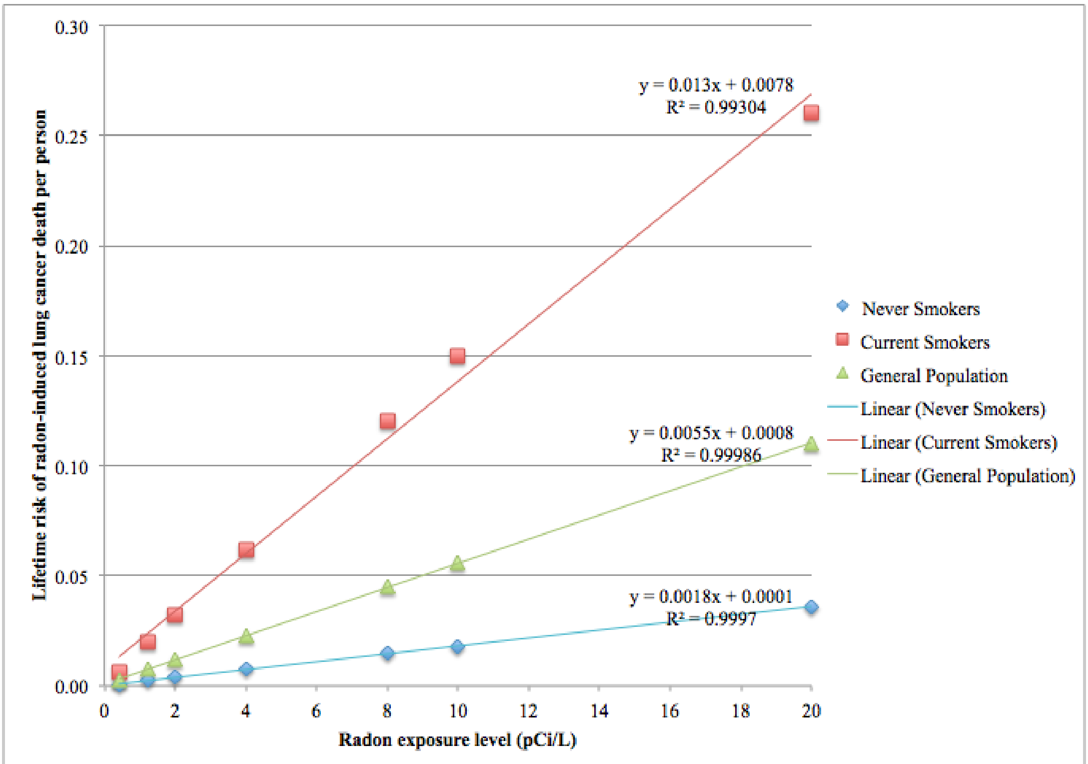


Figure 2.1. Dose-response relationship of radon exposure in the U.S. by smoking status. Lifetime risk of lung cancer deaths obtained from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).

Table 2.1. Summary of data collected from VDH and Peter Crowley

	Private Homes	Schools
Cost of Mitigation ($)	1,800	4,000 - 75,000
Type of Mitigation	Sub-slab Suction	Sub-slab Suction
Operation Costs	73.58	367.90

Building a Cost-Benefit Model (CBM)

<u>Overview</u>

The CBM uses the data that we have collected (Table 2.1) to calculate (i) monetary cost of abatement, (ii) monetary benefit of mitigating radon levels to below the EPA action level of 4 pCi/L and (iii) non-monetized mortality risk reductions. This model is applicable at the scale of a

single household and can be extrapolated to understand the cost-efficiency of radon mitigation in schools.

Whenever possible, we used Vermont-specific data, relying on data from the national population when necessary. For schools, we made the decision to perform the calculations assuming that only students populate schools. In Vermont, the faculty/staff to student ratio in public schools from K-12 is 1:10. We decided to exclude the population of faculty and staff from the calculations to focus mainly on radon's effect on children. This decision was due to a lack of data for the number of faculty and staff as well as the desire to support policy that focuses on risk reduction for children.

(i) Calculating cost

Total cost, TC, is the sum of the capital cost of installing the technology and a summation of all the years of the cost of running the technology for each year multiplied by time-weighted opportunity cost (Equation 1).

Equation 1. Total Cost

$$TC = C + \sum_{t=1}^{t=T} (O + M)\,(1 + r)^{-t}$$

C=capital installation cost
T=years that radon is mitigated
O=operational cost
M=maintenance cost (only factored in during a year that maintenance is required, once every 20 years)

Calculating the total cost (TC) of mitigating radon required knowledge of (1) initial installation cost, (2) operation cost by year, (3) maintenance cost per maintenance event, (4) opportunity cost as measured by discount rate, r and (5) the number of years radon is mitigated, T.

(1) Initial installation costs were assumed to be the median values for private homes. For schools, because the range is much greater ($4,000 to $75,000), we performed the analysis for low cost ($4,000), medium cost ($39,500, the average between $4,000-$75,000) and high cost ($75,000).

(2) For sub-slab suction, yearly operating cost is the cost of electricity required to run a fan unit(s) for 24 hours a day, 7 days a week, 365 days a year. In a private home, we assumed one fan unit would be used (Peter Crowley, personal communication) and obtained an operating cost of $70.96 per year from the most popular radon technology company's most popular fan, the RP145. (RadonAway 2012). An additional $2.62 was added on to this cost (totaling $73.58) to account for the environmental cost of air pollution per fan. In schools, the operating cost is $367.90 per year which is the operational and environmental cost of a private home multiplied by five, assuming that each school will need five fans for mitigation.

(3) We factored maintenance costs (the cost of replacing the fan(s)), into the equation once every 20 years, the lifespan of a fan. In home scenarios, we assumed one fan would be used and replaced after 20 years. In schools, due to the increase in size, we assumed five fan units, each of which would be replaced after 20 years of use (Peter Crowley personal communication).

(4) In addition to (1) - (3), the cost has to be discounted to present value. This reflects the opportunity cost of money spent on radon mitigation that can no longer be spent on other investments that earn a discount rate of r. For example, the money that could have been held in a savings account, accruing a discount rate of 0.03% per year, is spent on radon mitigation now and therefore offers no payback. The money, as well as the interest that could have been gained on that money, were included in the calculation of total cost. Regarding our choice of discount rates, r, one Danish study asserted that "6% is used as a basic value in accordance with most studies," but other countries suggest a discount rate less than 4.3%, as evidenced in the use of r = 4% by a U.S. study (Petersen and Larsen 2006; Ford et al. 1999). These discount rates take the perspective of the government rather than private costs and benefits, since they are exploring the possibility of implementing state policy requiring the state to pay for mitigation. For the home scenarios, we used three separate r values to reflect that the money an individual homeowner spends on radon mitigation could have been invested in bank savings (r = 0.03%), a government bond (r = 1.48%) or retirement (equity, r = 5%). For schools, we choose an r of 6%, based on the above review of studies, to reflect a discount rate representative of "state-spent" costs.

(5) The number of years that radon is reduced, T, is defined by the time difference between the decision to mitigate and the death of the homeowner. In a private household, we calculated T as the difference of the median age of natural death (79 years old) and the median age of people (42 years old) in Vermont. In schools, because we assumed that only students populate the

school, T is the difference between the median age of death in Vermont and the median age of K-12 students (12 years old). While we recognize that students do not stay in school for their entire life, we assume that the building itself will always be populated by students of the average age and thus the benefit is always accrued. The change in risk (difference between pre- and post-mitigation risk levels) is multiplied by this number of years.

(ii) Calculating benefit

Total benefit (TB) of mitigating radon is the (6) change in risk of death from radon-induced lung cancer, standardized by the percentage of the lifetime over which radon is mitigated, multiplied by (7) the total value of the life years saved from an avoided death, multiplied by (8) the population exposed (Equation 2).

Equation 2. Total Benefit

β

$$TB = [(\beta(\Delta\, radon))(T/ND)]\ (VSLY)_{\Delta DA}(P)$$

β = slope of the dose-response relationship
Δ radon = change in pCi/L
T = years that radon is mitigated
ND = age of natural death
$VSLY_{\Delta DA}$= see equation 3
P = exposed population

(6) Change in risk of mortality from radon-induced lung cancer depends on the quantity of radon reduced. Understanding changes in risk requires data on pre- and post-mitigation radon levels, as well as the dose-response relationship for radon exposure (i.e. the corresponding reduction in mortality risk due to a reduction in radon levels). We assumed that only houses with pre-mitigation readings above the action level will mitigate and that mitigation will reduce radon levels in houses to the action level, since radon mitigators will guarantee radon reductions to the action level or below (Peter Crowley, personal communication, March 12, 2015). Hence, only pre-mitigation levels above the action level were considered in this analysis and all post-mitigation levels are assumed to be at action level.

To understand the change in risk we took the median radon level in each of the radon scenarios, low (4-10 pCi/L), medium (10-30 pCi/L) and high (above 30 pCi/L) and subtracted 4

pCi/L (the EPA action level) from the median to obtain the median amount of radon mitigated in each scenario (Table 2.2). We used these three mitigation values in the CBM to calculate the median amount of risk reduced in each radon scenario given mitigation.

Table 2.2. The median of radon levels in low, medium and high radon scenarios.

	Median radon level of each radon range (pCi/L)	Median radon reduction due to mitigation (pCi/L)
Low radon range (low risk, 4-10 pCi/L)	5.7	1.7
Moderate radon range (moderate risk, 10-30 pCi/L)	13.4	9.4
High radon range (high risk, >30 pCi/L)	40.7	36.7

Additionally, we were able to calculate the reduction in risk for smoking, non-smoking and the general population based on the different dose-response relationships (Figure 2.1). In both private homes and schools we chose to use the dose response relationship for the general population. In further analyses, we manipulated this variable to understand cost-benefit comparisons for smoking and non-smoking populations.

(7) The value of avoiding mortality from radon-induced lung cancer (Equation 3) is defined as the summation of the Value for a Statistical Life Year (VSLY) (Regulatory Impact Analysis for the Final Section 126 Petition Rule) over the years saved by avoiding death due to radon induced lung cancer. No matter the age at the time of mitigation, the years saved in avoiding death will be those between age 72 (average age of death from radon-induced lung cancer) and age 79 (average age of natural death). As in the equation for total cost, this value was discounted back to present value (Equation 1 (4)).

Equation 3. Value of avoiding death from radon-induced lung cancer.

$$VSLY_{\Delta DA} = \sum_{t=(RDA-EA)}^{t=T} (VSLY)\,(1+r)^{-t}$$

RDA= age of radon-induced lung cancer death
EA=age of exposure
VSLY= value of a statistical life year

(8) We assumed the population exposed in a private home to be the average number of people per household in Vermont (2.34). In schools, this number is 255.28, taking total number of K-12 students in Vermont public schools (79,646) divided by the number of public schools in Vermont (312) (Vermont Department of Education 2014). Table 2.3 summarizes the different abatement scenarios used for a typical private home and school in Vermont.

Table 2.3. Variables used in the Cost-Benefit Model for a typical private home and school

	Private Home	**School**
Technology used	Sub-slab suction	Sub-slab suction
Cost of abatement ($) • Low • Medium • High	 - 1,800.00 -	 4,000.00 39,500.00 75,000.00
Operation cost/year ($)	73.58	367.90
Maintenance cost/event ($)	149.00	745.00
Discount rate (r) (%) • Low (Savings account) • Moderate (Bond) • High (Equity) • State spent	 0.03 1.48 5.00 -	 - - - 6.00
Number of people exposed	2.34	255.28
Median age of people exposed	42	12
Median age of natural death (VT)	79	79
Median age of lung cancer death (VT)	72	72
Years of risk mitigated	37	67
Years of life saved	7	7
Smoking status • Smoking • Non-smoking • General population	 - - yes	 - - yes

An Alternative Approach

As we worked through the model, we recognized how the VSLY greatly impacted the results and that reputable sources (the EPA, EU, WHO) disagree on this value. An alternative way of analyzing this issue without placing a value on a life year is to calculate the dollar amount necessary to reach 100% chance of avoiding the risk of death from radon induced lung cancer

based on the dose response relationship. In other words, we found the dollar per life saved, which can be used as a way to standardize and prioritize comparisons in risk reduction across other public health concerns.

Results

CBM Results

Our analysis has revealed that across all risk scenarios the benefits of radon mitigation outweigh the costs. In technical terms this means that for each of our calculations, the benefit to cost ratio was above 1. In the average Vermont private household, the benefit to cost ratio was highest in the high radon reduction scenario of 36.7 pCi/L reduced in the home. Within this reduction scenario the ratio was highest with a low discount rate (0.03%) followed by a moderate rate (1.48%) and finally a high rate (5%). This trend was consistent within both the moderate and low reduction scenarios with the low reduction scenario resulting in the lowest overall benefit to cost ratios (Figure 2.2).

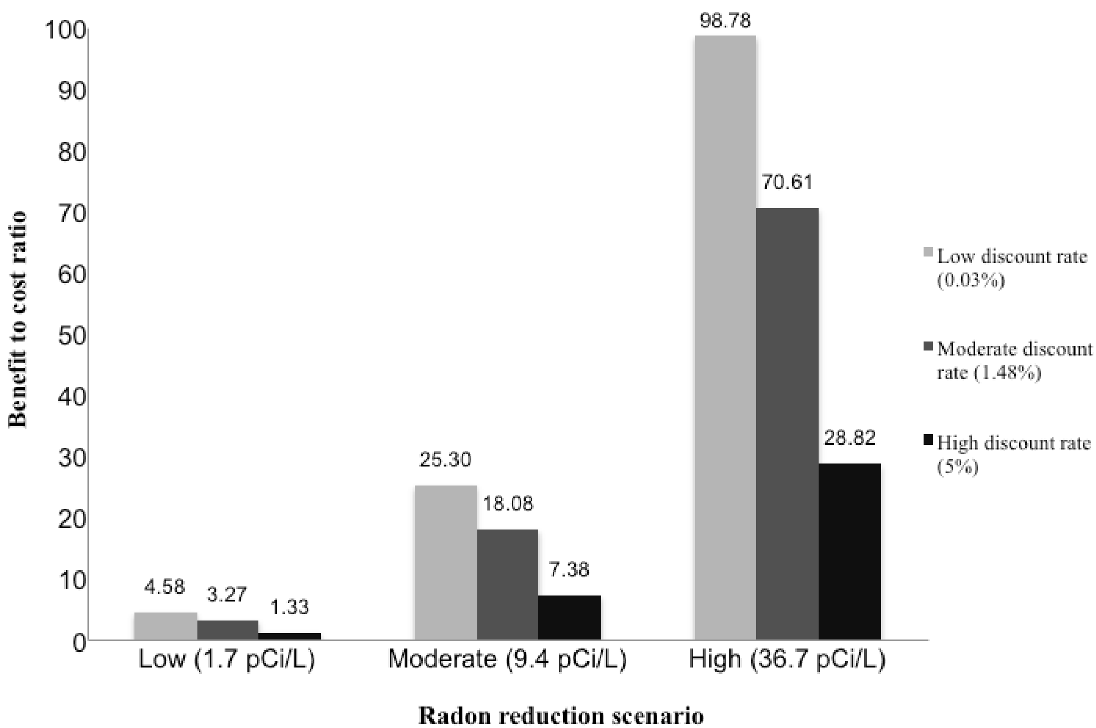


Figure 2.2. Benefit to cost ratio for abating radon to action level 4 pCi/L in private homes for different radon reduction scenarios, with different discount rates.

In Vermont schools, it is also clear that radon mitigation offers more benefits in terms of risk reduction than costs associated with installation, operation and maintenance of mitigation systems. Similar to private homes, the benefit to cost ratios calculated for schools were highest in the high-risk scenario, regardless of abatement costs. Within abatement costs, the low cost estimate had the highest cost/benefit ratio, followed by the medium and high cost estimates for abatement in schools (Figure 2.3).

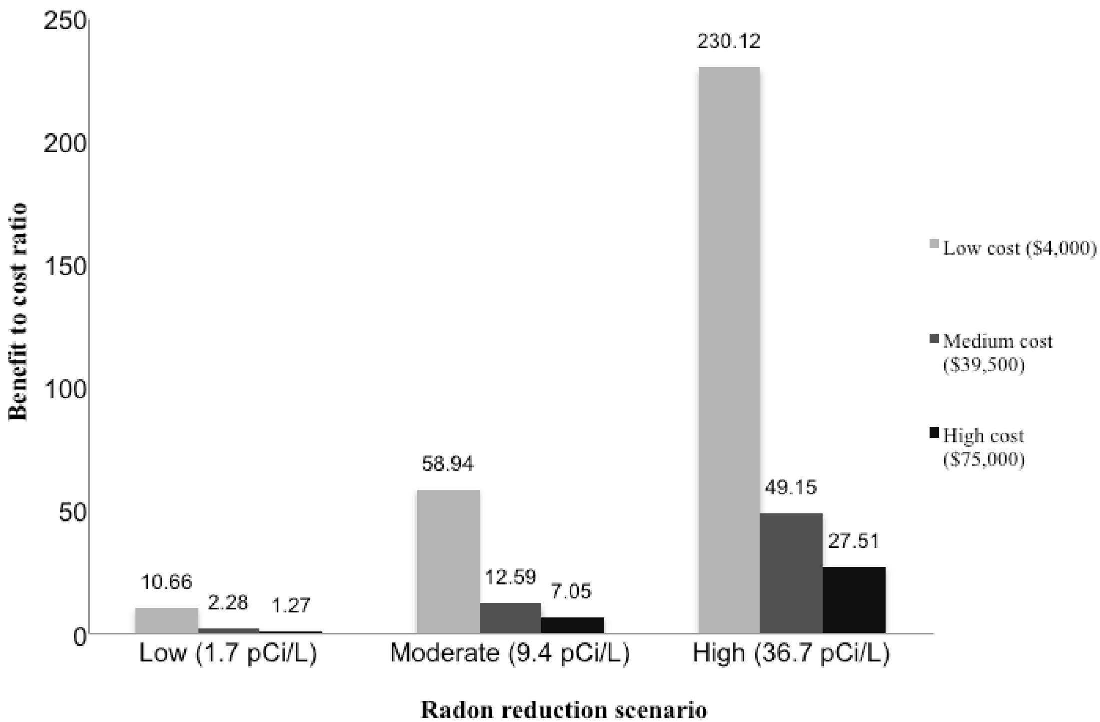


Figure 2.3. Benefit to cost ratio for abating radon in schools for different radon reduction scenarios, with different installation costs.

Finally, radon mitigation is still cost-effective when comparing between a smoking population and non-smoking populations. Again, ratios are largest in the high reduction scenario and there is a large difference between smokers and nonsmokers. In each risk reduction scenario, the benefit to cost ratio is much higher for smokers than nonsmokers (Figure 2.4).

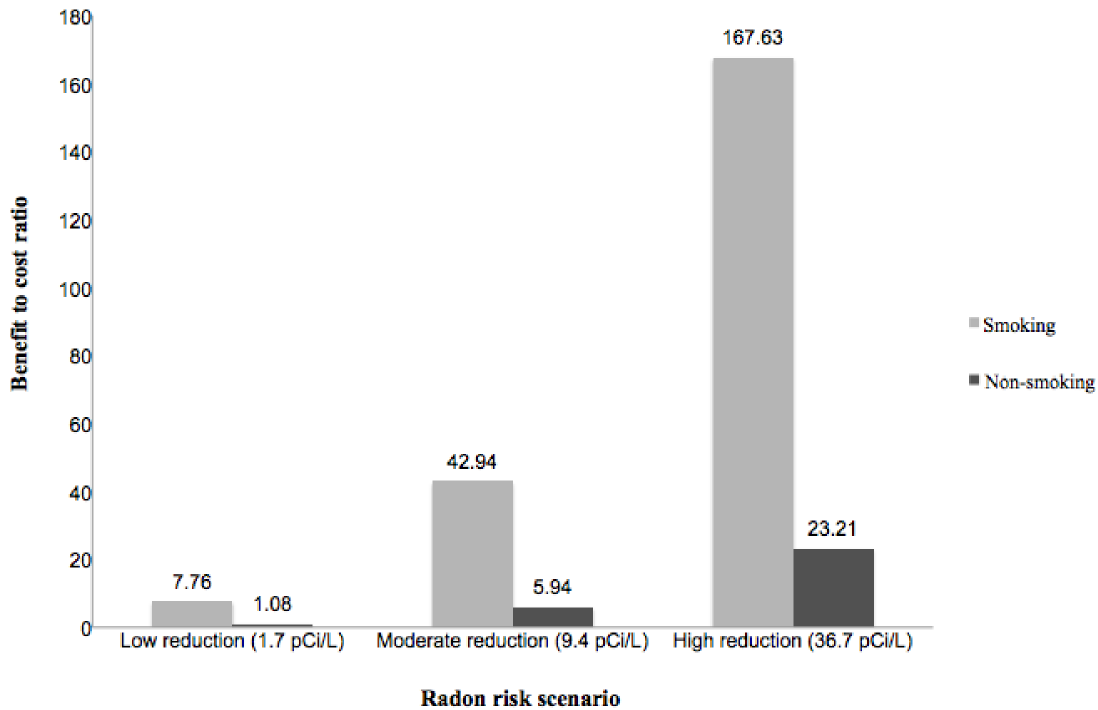


Figure 2.4. Benefit to cost ratio for abating radon in private homes for different radon reduction scenarios for smokers and nonsmokers.

Calculating Dollars/Life Saved

To calculate the cost of one life saved (avoiding one statistical death from radon-induced lung cancer), we maintained all variables at the moderate level, a radon reduction of 9.4 pCi/L and the linear dose-response relationship for the general population (Figure 2.1). For a single individual in that moderate scenario, the decision to mitigate yields a change in risk of 0.0517. Because there are an average of 2.34 people in each Vermont household, we multiplied that change in risk by the number of residents to represent the change in mortality risk by household (0.120978). In dividing the average installation cost for a single household mitigation ($1,800) by the household change in risk (0.120978), we arrived at the cost of one life saved, $14,879. This is equivalent to mitigating about 8.3 homes with a moderate radon reduction in order to save one life. This number does not include the operation and maintenance costs due to the model's sensitivity to discount rates and VSLY. Therefore, this cost represents a snapshot in time at the point of installation. Of course, we cannot completely eradicate an individual's risk of mortality from radon-induced lung cancer. Rather, the dollar per life saved represents the cost of avoiding one statistical death when risk reductions are combined across a given population.

Similarly, in the school scenario, we multiplied the change in risk of radon-induced lung cancer death (.0517) by the number of children in the average Vermont school (255.28) to get a change in this risk per school building (13.197976). We then divided the medium cost of mitigation system installation in a school building ($39,500) by the change in risk to get $2,993 per life saved, or about 0.076 schools with a moderate radon reduction for one life saved.

A moderate radon reduction level of 9.4 pCi/L, however, is rare in Vermont. Based on the distribution of testing data in Vermont, over 80% of radon test results above the action level would have a median reduction of 1.7 pCi/L corresponding to our determined low range. Hence, using the same methodology described above, for the vast majority of Vermont homes and schools, the cost per life saved would be $82,271 in a household scenario, or $16,549 in a school scenario. This is equivalent to mitigating 45.7 homes, or 0.42 schools to save one life.

Discussion

<u>Main Results</u>

Of course, given a limited budget, cost-effectiveness does not guarantee the feasibility of action on the state level. For the sake of decision-making, we can compare the relative efficiency (the ratio of benefits to costs) of mitigation across infrastructures and across risk levels. There are at least three important generalizations that can be made when cost efficiency is compared.

1. The lower the discount rate, the more cost-effective.

While the discount rate is considered on both the costs and benefits sides of the equations, it has a greater impact on the cost because the benefits of any action happen so many years in the future and thus the act of discounting back to present value softens the impact of the rate.

2. The higher the radon concentration pre-mitigation, the more cost-effective.

Ultimately, the amount of radon reduced is not a factor in the cost of mitigation. Instead, mitigators charge based on the complexity of the structure to be mitigated because most of their costs are based on labor and materials used. When comparing cost to benefit, in structures where there are high levels of radon, the homeowner gets the most “bang for their risk reduction buck” because cost is not based on radon level. Homeowners with similar houses will pay the same amount for their mitigation system even when one has 40 pCi/L and the other has 5 pCi/L radon. Homeowners with high levels of radon can reduce higher amounts of risk for less than homeowners with lower levels of radon.

3. Mitigation is more cost-effective for smokers.

The steeper slope of the dose-response curve directly informs the increased cost-effectiveness for smokers. Because the cost of mitigation is relatively fixed and the benefit is calculated from a change in risk represented by two points on the curve, the greater the interval between those two points, the more cost-effective the mitigation.

<u>Assumptions</u>

Our model is a place to begin. It is imperfect and resting on several important assumptions that would be irresponsible not to acknowledge. We assume that there is a linear dose-response relationship for radon exposure, meaning the higher the exposure to radon, the greater the risk of radon-induced lung cancer (Figure 2.1). The general community of radon analysts accepts that the dose-response relationship is linear. It is also accepted that the slope of this relationship increases for the smoking population due to the synergistic relationship between smoking, radon exposure and risk of lung cancer (Sethi et al. 2012; Lantz et al. 2013; Rinker et al. 2014). EPA guidelines based on its "Guidelines for Carcinogenic Risk Assessment" publication corroborate our assumption (Environmental Protection Agency 2005). The linearity of the dose-response relationship is an informed extrapolation; however, more epidemiological research specific to radon exposure is needed before this assumption can be validated.

Another assumption associated with the linear dose-response relationship is that exposure is constant over a lifetime. This excludes possible variation in risk due to exposure varying over time periods. For example, we know that levels of indoor radon fluctuate with the change in seasons; how does this influence exposure and consequently, how does this vary risk? Further, the dose-response relationship that we have drawn on is derived from data on uranium miners (BEIR VI, 1999). Though we recognize the challenges inherent to epidemiology, we believe that more research, particularly research based on the general population, will increase the accuracy of a model such as our own.

We've made simplifications in our model for the ease of communication. The model must be controlled in order to understand the effect of individual variables in greater detail. In our analysis we value the median cost for radon mitigation at $1,800. This is limited in that it is only representative of costs from sub-slab suction mitigation techniques. Radon mitigation methods range from very passive techniques, such as standard ventilation, to extremely active techniques

like an Energy Recovery Ventilation system. Including other mitigation techniques would cause a change in our median cost, resulting in a shift in our benefit to cost ratios.

Smoking

Smoking has a positive synergistic effect on the risk of mortality from radon-induced lung cancer. Radon is the second leading cause of lung cancer and also increases the risk of lung cancer in smokers. Radon-induced lung cancer is potentially caused by damage to cells by alpha particles through the production of a reactive oxygen species (Sethi et al. 2012). Acknowledging that an estimated 21,000 lung cancer deaths per year are attributable to radon and that smoking increases risk, smoking cessation must accompany mitigation to reduce risk.

Although mitigation is much more cost-effective for the smoking population due to the slope of the corresponding dose-response relationship, targeting smokers is not a popular policy option. Smoking is viewed as a personal choice and in this case the consequences of this choice increase the risk to health. The State already invests significant resources into smoking cessation from smoke-free laws to youth prevention programs. Under Vermont's Fiscal Year 2013 Appropriations Bill, the "Sustainability of Tobacco Control" allocated $3,971,713 for Fiscal Year 2016 (Morabito 2014). Therefore, it is not likely that specific funds will be allocated to target radon reduction for smokers despite high potential benefits.

Health Cost Tradeoffs

Lung cancer is an expensive illness to treat and represents a substantial burden to the health care system in Vermont. Due to our understanding of the dose response relationship for radon, we can assume that radon mitigation in Vermont will result in a reduction in the incidence rate of lung cancer attributable to radon. The average age of lung cancer incidence is 70 in Vermont. As this illness impacts the elderly with the most frequency, we infer that the cost of this treatment is borne primarily by the state through programs such as Medicare and Medicaid. By reducing the incidence rate of lung cancer attributable to radon, we can expect to see monetary benefits through cost reductions to the healthcare system (VDH, 2010).

The average annual cost of lung cancer treatment in 2000 was $56,385 per patient (Cipriano, et al. 2011). When adjusted for inflation, the annual cost in 2015 is $78,668 per patient (USDL, 2015). According to the Vermont Department of Health, on average 58 people a year are

diagnosed with lung cancer that is attributable to radon; treatment for these cases results in an average annual cost of $4,562,744 to the healthcare system (VDH, 2010).

The monthly costs for lung cancer treatment in 2000 ranged from $2,687 to $9,360; this is representative of patients receiving no active treatment to patients receiving chemo radiotherapy (Cipriano, et al. 2011). Due to the aggressive nature of lung cancer and the average stage of diagnosis, treatment costs are primarily comprised of patients receiving chemo radiotherapy; meaning there is a significant chance that the average costs listed above are an underestimate (VDH, 2010). In addition, using the average incidence rate yields a cost value that is concrete, but it is not representative of all individuals being *currently* treated for radon-induced lung cancer. Although both the federal government and the state provide public funding to the healthcare system, these healthcare costs still present a significant burden. It would be more cost-effective to mitigate and decrease incidence than to treat lung-cancer attributable to radon.

Socioeconomic Status and Radon

Incorporating socioeconomic attributes such as race, gender, income level and education level raises ethical, political and moral issues. Different socioeconomic groups do not have the ability to mitigate equally and therefore it is necessary to pay attention to these implications. We chose to avoid valuation of these categories for this reason. While understanding the implications of these decisions, policymakers make explicit or implicit tradeoffs constantly. The current literature is not refined enough to make valuations across demographics and the EPA should continue to calculate VSL without regard to socioeconomic categories (Stavin 2000). Valuations across age categories may be relatively acceptable because all people will belong to every age group in their lifetime. In all other socioeconomic categories, the sources of these differing burdens can be identified and discussed without adding valuation (Stavin 2000).

Radon reduction plans and related costs must be analyzed from the perspective of the private individual as well as the state to understand the implications of radon policy decisions. The average cost of the abatement for a private home is $1,800. The median income level in Vermont for 2009-2013 is $54,267 (United State Census 2013). Additionally, in 2010 the Gini Coefficient, which measures income inequality on scale of 0 (total equality) to 1 (total inequality), rated Vermont at 0.441 or 19th nationally. Since mitigation cost is a higher financial

burden on low-income households than for higher income households the ability to mitigate varies across income status.

Other cost-benefit analyses have found it is not worthwhile for the state to pay for mitigation programs that reduce radon levels in dwellings to below the action level (Petersen and Larsen 2006). Our analysis found that the cost-benefit ratio was above 0 for all three levels of mitigation. However, the higher the initial amount of radon, the higher the benefit from mitigation a homeowner would accrue. This finding is supported by our conversations with Peter Crowley, concerning roughly equivalent costs of reducing radon risk to action levels (4 pCi/L or 2 pCi/L) regardless of pre-mitigation level.

We have seen that the cost burden of radon testing varies in terms of the radon reduction framework plan the government has in place and the concentration of radon. For example, a Canadian study analyzed the cost effectiveness of implementing a comprehensive radon reduction plan that focused, not only on mitigation, but also on all aspects including testing and education. In order to increase cost-effectiveness they determined efforts should be spatially focused on areas of high radon levels and implemented with a lower acceptable threshold of radon exposure (Letournaeu et al. 1992).

In order to avoid the moral, ethical and political complications of incorporating differences across socioeconomic categories, it is preferable to contextualize policy decisions without making valuations. Vermonters have different abilities to pay to mitigate radon and the state currently ranks 19th in state income inequality. However, it is truly impossible to completely sidestep these complications as policymakers are forced to make these tradeoffs all of the time. While there is state recognition that radon is a health problem and the state currently supports individuals in education and testing of radon, there is no support for mitigation (Vermont Department of Health 2015).Without support for mitigation, individuals are left with the burden of the knowledge of their risk without the means to change their situation. Therefore, our analysis considers the cost-benefits from both the perspective of the private individual and state-sponsored school mitigation. Both of these perspectives are necessary to understand how policy decisions from the state affect the individual’s ability to mitigate.

Export of Risk

While mitigating for radon in the state of Vermont will reduce the incidence rate of lung cancer here and result in a monetary benefit in health care dollars saved, a portion of mitigation costs may be exported outside of Vermont state boundaries. We sought to quantify that risk, given the potential for an impact on the healthcare system (necessarily a country-wide issue).

Vermont exists within the Northeast Power Coordinating Council (NPCC) region of the United States. For the most part, energy used in Vermont is generated within the NPCC region. According to the EPA, there are 705 plants in operation. Of those 705 plants, 451 do not rely on fossil fuels as a primary source of energy (64%). Of the remaining 254 plants, 151 run primarily on natural gas (21%), 84 on oil (12%) and19 on coal (3%) (EPA 2010). If electricity used in the state of Vermont was distributed across fuel types proportionally to the distribution of plant types, each kWh would have gross external damages (GED, including a \$27/*t*C social cost of carbon) of 0.005541 dollars per year (calculations based on Muller et al. 2011).

A single household, drawing 473 kwh/year to power mitigation technology alone, is responsible for 2.62 dollars of gross external damages per year. While we recognize that mitigation is not necessary, let alone cost effective, for every household in the state of Vermont, we can expand our understanding of the trade-offs by multiplying that cost (\$2.62) by the total number of Vermont households (272,650). If every household in the state of Vermont were to install an energy intensive mitigation technology, we, as a state, would be exporting a gross cost of \$714,343 each year. \$714,343 is just less than the annual cost of treatment for ten lung cancer cases (\$78,668 per patient). Given the assumed 50 cases of mortality from radon-induced lung cancer in Vermont, we argue that benefits of mitigation would outweigh costs on the healthcare system from a holistic perspective. Of course, the exported risk calculations here report a relatively low number only because of the relatively clean grid from which we are drawing here in the Northeast. The exported cost might look similar in the western region of the United States but without a doubt would increase in more coal-intensive regions such as those in the southeast part of the United States.

Additional Considerations in Valuing Statistical Life

In our analysis, we chose to conduct a cost-benefit model for mitigation and to monetize the benefits. Monetizing the benefits of mitigation allows for the comparison across many policy benefits. Both VSL and VSLY do this but they differ in that VSLY includes the multiplication of expected life years saved. While VSL is more of a measure of the willingness of an individual to pay for risk reduction, VSLY values the reduction of mortality risk in relation to the life years gained. The difference between average life expectancy and age of death from lung cancer is 7 years and the benefit of these years can be multiplied across an individual's life. VSLY better captures the benefit that occurs in those 7 years than VSL.

Despite our decision to pursue VSLY, the debates about the creation of VSL are informative to the discussion of evaluating potential policy benefits. The EPA uses VSL and recommends the central estimate of VSL at $7.9 million (2006 U.S.$), regardless of age, income or other demographic characteristics. In comparison with other U.S. agencies, the EPA has developed more costly guidelines responsible for guiding regulatory impact analyses. The EPA's figure for VSL is also significantly higher than other cost-benefit analyses conducted outside the U.S.. The European Union Directorate General Environment values the prevention of a statistical fatality at between 0.9 million and 3.5 million euros and recommended the use of 1.4 million euros as the best estimate for a statistical fatality, or VSL (European Commission, 2001 in Petersen and Larsen 2006). The WHO also recommends this value (1999) (Petersen and Larsen 2006). When converted to U.S. dollars, using the 2000 exchange rate and adjusted for inflation between 2000 and 2015, this figure is $1,783,466.

This VSL is tremendously lower than the EPA's suggested value of $7.9 million. In addition, the Danish study adjusted for age and Danish purchasing power (although these adjustments effectively counterbalance each other), while the EPA is hesitant to support alterations to the VSL due to the controversial nature of placing more value on certain lives over others. If we had utilized the EU- and WHO-recommended VSL, it is likely that our understanding of the relationship between cost and benefit when mitigating for radon would be drastically different. Some laws do not allow the consideration of economic cost; however, it is necessary for a budget-limited agency to understand the regulatory costs, individual costs and mortality.

Dollars/Life Saved

'League tables,' which are tables designed to exhibit the relative standing of one thing in relation to another, most commonly used to compare companies, have found their place in the sphere of public health. They have been used on a scale as big as the Federal Office of Management and Budget's (OMB) comparison of the cost-effectiveness of regulations across three of the country's largest Federal agencies, the Department of Transportation, the Occupational Safety and Health Administration and the Environmental Protection Agency (United States White House 2001). The OMB measured dollars per life year saved (both discounted back to their present value) and recommended that the table be used to support regulatory decision-making.

Of course, uncertainties arise here too; the same dose-response relationship is necessary in determining life years saved; furthermore, when saving one life in terms of radon-induced lung cancer, what you are really getting is a benefit of seven years (79 minus 72 years of age). While we can compare the cost of one avoided death across issues, it is worth thinking about the trade-offs between avoiding the death of a child from lead exposure and avoiding the radon-induced death of someone much older. We are hesitant though, to make any quantitative assessment of value differentiated by age. That said, we recommend that the Vermont Department of Health follow-suit in the construction of a League table comparing the cost-effectiveness of their various public health issues. Much like the model that we've created here, the dollar/life year saved ratios will be based on imperfect information, but still they offer a framework to return to.

Recommendations

We recommend that the VDH not only seek to improve the accuracy of the dollar/life saved metric with respect to radon, but also begin to compare the metric across issues. Our work demonstrates the importance of the dose-response relationship and the uncertainties that we've presented call for the re-examination and refinement of that relationship. The normalization of a dollar/life saved comparison across issues will encourage cross-issue communication within the VDH. A strategically distributed budget could make for a healthier Vermont!

Conclusions

We began with a question of the cost-effectiveness of mitigating radon in the state of Vermont. We've uncovered the complexity of cost-benefit analyses in the context of epidemiology and especially with respect to naturally occurring environmental contaminants for which there is no safe level of exposure.

In an analysis such as the one that we've done, it is easy to lose sight of public health as a big picture. The mitigation question does not begin and end with radon as a single issue. Rather, it is situated within a landscape of questions, all of which introduce their own degree of complexity and uncertainty. We began with a question and we will end with several more: How accurate is the dose-response relationship in representing the risk of exposure to radon? What costs and/or benefits of mitigation have we neglected to represent? Could mitigating radon present new risks of lead (a byproduct of radon decay) exposure as more radon is pulled up from the ground and dispersed in the area around the home? Are there other contaminants entering the home whose risk is avoided when sub-slab suction is employed (e.g. moisture management/mold/allergens)? What is the significance of a finding that determines cost-effectiveness when deciding whether or not to mitigate? How does the cost-effectiveness of radon mitigation compare to the mitigation of other environmental contaminants that pose a threat to human health? Will findings such as these have any bearing on the decisions of individuals? The state? The country? We hope that our findings (and questions alike) will inspire more questions, further study, and healthier lungs.

Chapter 3. Raising Radon Salience in Vermont

Introduction

To understand the need for a Salience Team within this semester's Environmental Studies Senior Seminar project, it is important to recognize some of the factors that make radon a challenging public health topic. As a tasteless, odorless, invisible, and naturally-occurring gas, radon is undetectable without testing. Buildings constructed in areas of uranium-rich bedrock or soils can develop high concentrations of radon in indoor air, and this poses a significant health threat when paired with the fact that the average American spends approximately 90% of their time indoors (Hancock, 2002, in Hill, Butterfield, & Larsson, 2006). Radon ranks as the second leading cause of lung cancer and the seventh leading cause of overall cancer mortality for the United States (Field, 2012). At the national scale, radon is associated with 15,000-22,000 deaths per year (Field, 2012). The state of Vermont has an incidence of high home radon levels that is nearly twice the U.S. average (Vermont Department of Health, EPA's Citizen's Guide to Radon, 2013). A 1998 Harvard University study conducted by DeAscentis & Graham ranked "inhalation of radon gas as the leading in-home hazard ahead of firearms, fire, poisoning, and falls. Yet radon gas appears to be one of the most underestimated and misunderstood threats to public health" (DiPofi, LaTour, & Henthorne, 2001 *in* LaTour & Tanner, 2003).

Despite the risk to health posed by radon, Vermonters remain relatively unaware of this issue. Chief among salience issues in Vermont is radon's natural geologic origins. Without a responsible party to vilify or a clear sense of personal responsibility that falls on any one individual, raising awareness concerning radon runs headlong into several important psychological biases that people rely on to reduce the cognitive demands of threat. Given the low salience of the radon threat in Vermont, the state has not developed any legislation for mandatory radon testing, and limited funding and resources for education and outreach concerning radon contribute to approximately 50 annual radon-caused cancer deaths in Vermont.

As partners with the Vermont Department of Health (VDH) and the American Lung Association (ALA), the Salience Team was tasked with increasing radon awareness and testing.

After initial conversations and research, it is clear that awareness is a hindering factor for individuals testing and choosing to mitigate radon in a state that reports levels of radon above the EPA action level in one out of eight homes (Vermont Department of Health). Due to this low awareness, we have decided to take an overall approach of education and public outreach. Although different types of education and outreach will identify specific goals later in this report, our overall goals are to increase awareness and understanding of radon, as well as its associated health risks, among Vermont residents.

To successfully achieve these goals, the team worked in three distinct, but interrelated subgroups: Research and Outreach, Narratives, and Education. The Research and Outreach subgroup conducted research and created the following literature review on effective radon outreach. This research helped frame and inform the approach of the salience team at large. Also directed by this research, the Research and Outreach subgroup developed targeted outreach materials for Vermont residents, focusing on print ads and an informational video. The Narrative subgroup composed a narrative detailing a firsthand account from someone personally impacted by radon-induced lung cancer, with the hope of drawing attention to the potential consequences of high radon levels in one's home, school, or workplace. This narrative will hopefully inform and motivate Vermont officials in their consideration of some level of statewide policy (as detailed in the Policy chapter). Finally, the Education subgroup developed an easily replicable service-learning project which enables local high school students to simultaneously complete public service while educating middle school students about environmental contaminants with a focus on radon. This report outlines our recommendations for communicating the issue of radon to the Vermont public in three distinct ways, as supported by the existing literature on radon and fear appeals.

Literature Review

In 1993, Sandman & Weinstein carried out a study with over 3,000 participants to determine the factors that predict an individual's interest in carrying out home radon testing. This study delineates 5 major stages for radon awareness and concern: 1) unaware of radon problems, 2) aware of radon problems but no thought of testing one's home, 3) thinking about testing, 4) deciding to test, and 5) carrying out a radon test. Sandman & Weinstein determine a series of variables (e.g. knowledge of radon, perceived likelihood of home radon problems) that are

connected with people moving between the stages from no awareness to testing for radon. Their stage model identifies the differing variables that predict moving between each stage. Though this may sound simplistic, this finding, and the identification of the different variables, is important for outreach purposes as it highlights the need for varied materials that address an audience that is heterogeneous, both in terms of radon knowledge and initial interest in testing.

The authors condense these five steps into three primary ones: 1) thinking about testing; 2) deciding to test; and 3) testing. This is the basic stage model that we used to frame our independent research on outreach practices, and we decided to include an additional Stage 0 as a baseline (absolutely no knowledge of radon or radon's health effects). The focus of our outreach work is focused primarily on moving Vermonters from stage 0 (no knowledge) up through stage 2 (deciding to test) given the generally low salience of the radon problem in Vermont and the need for current campaigns that maximize radon awareness.

As a team, we compiled research from the fields of radon outreach, environmental psychology, and fear studies in order to identify and understand the most effective ways for increasing awareness and promoting action related to the issue of radon in Vermont. In line with Sandman & Weinstein's (1993) stage theory, we fit research and findings into the distinct stages. This decision was motivated by the purposefully broad-scale nature of the research with the intention of maximizing outreach impact to a primarily non-target audience. Instead of adopting this non-targeted approach, we utilized two parts of Sandman & Weinstein's (1993) research. The first finding indicates that a number of different factors are important in moving people between stages, and important at different times, given heterogeneous populations in terms of radon knowledge and interest in testing. The second finding is that effective outreach is dependent on isolating distinct audiences so outreach appeals meet the particular needs of the audience. Therefore, to make outreach most effective, the materials were developed with specific target audiences in mind, diverging from the one-size-fits-all style findings presented by much of the literature.

Another factor that played an important role in determining outreach best practices was what we refer to broadly as lifestyle differences in our population. In looking at materials created by the VDH, the EPA, and Departments of Health in other states, we found that there was a distinction between radon materials intended for professionals in industries related to radon (for example, home-building, mitigation) and laypeople; however, within this latter category, the

materials appear to once again be one-size-fits-all resources that fail to take into account the level of audience awareness (see the above steps) nor lifestyle choices that have major implications for what outreach would be most effective. As part of our efforts in getting individuals to test for radon (Stage 2), we accounted for different target audiences determined by lifestyle factors (for example, smokers, parents, school administrators, construction professionals, future homeowners, lung-cancer patients), and adapted our outreach materials according to their awareness level and overall lifestyle.

Stage 0: No knowledge about radon or its health effects

At the earliest stage for radon awareness, the goal for outreach materials is to bring the audience from zero knowledge of radon and its health effects, to knowing about the problem and towards thinking about testing. Acquiring a basic knowledge of radon is the most critical factor for this transition and is therefore the focus at this point of the model. According to our research, there are several critical components to consider when disseminating first-time information about radon as a public health problem.

According to the American Association of Radon Scientists and Technologists (AARST), the most basic part of early message delivery is to make messages about a public health problem both clear and personal (AARST, 2014). Messages about public health issues like radon are most effective when an audience identifies with the messaging, something that can be accomplished when outreach materials are designed to appeal to and convince a specific target audience. Clarity is also critical for both gaining and holding the audience's attention when introducing a new issue; confusing messaging when communicating the basics of radon can make it more difficult to move people towards Stage 1 in a way that promotes interest in testing.

Another important factor for early radon outreach is to team up with sources that would be considered credible by the target audience (AARST, 2014). Creating a foundation of trust (also related to the point of clear messaging) is important in ensuring that information is received in a way that facilitates moving towards testing/mitigating. Early-stage education that fails to engage or appear trustworthy to an audience can ultimately handicap radon outreach, as people can choose to ignore further messaging on the issue. By partnering with VDH and the ALA, we believe the message will reach a broader and more receptive audience.

In a similar vein, AARST recommends training industry leaders with connections to radon and public health matters (e.g. health care professionals, home builders, real estate agents) to disseminate radon information to their peers. By accessing these groups through peer relations, information about radon can be transmitted via a personally relevant and trustworthy group.

To make radon an understandable issue for an audience with no knowledge, AARST recommends comparing radon to very familiar risks when introducing it. Instead of using fear-inducing but uncommon threats like lightning strikes, it is more effective to introduce radon in terms of well-known health risks such as carbon monoxide or smoking (AARST, 2014). Another part of making radon tangible and clear for new audiences is preparing education and outreach materials with clear answers for frequently asked questions.

Stage 1: Thinking about testing

The focus of Stage 1 is to get people to think about testing their personal residence or work environment for radon. Sandman & Weinstein (1993) indicate that basic knowledge of radon needs to be supplemented with an awareness that others are concerned about radon, considering testing, or have already tested. Social proof becomes an important variable when getting an audience to move from Stage 0 to Stage 1. Social proof refers to the psychological phenomenon where people rely on the actions and opinions of others in the same situation to judge the value of a specific course of action (Rao et al., 2001). As AARST (2014) indicates, social proof for radon is most effective when highlighting local statistics and information about testing rather than national level information. By showing people that their peers (as narrowly defined as possible) are concerned about radon, their need for social proof in taking their own course of action can be positively manipulated to promote radon concern and testing.

As Sandman & Weinstein (1993) suggest, social proof for testing for radon can be encouraged with outreach that includes sharing narratives and trying to increase visibility of the people who have chosen to test (e.g. bumper stickers that people can use to show they have tested). By focusing these types of campaigns at a local level, the outreach materials were designed to trigger in-group identifications based on geographic locations, an identification that makes neighbors in a community act as social proof for caring about and testing for radon. To also trigger feelings of in-group identification, AARST (2014) recommends personalizing the

threat of radon with stories from people who share social and economic characteristics with the target audience.

The major focus of social proof, as a part of stage one, is to get people to seek out further information concerning radon, as “[h]oping for people to test and install mitigation systems as the result of a single ad stimulus is thought to be unrealistic, although an eventual desired end result. Therefore, the focus [is] simply to get homeowners to seek more information” (LaTour & Tanner, 2003).

Stage 2: Deciding to test

Stage 2 of Sandman & Weinstein’s radon awareness model (1993) marks the turning point between thinking about testing and deciding to test for radon. At this stage, the most important variable for deciding to test is the perceived likelihood of having a home radon problem. Even with a basic understanding of radon and social proof “evidence” that radon is an issue that should be taken seriously and tested for, radon runs into a number of cognitive biases that encourage individuals to underestimate the risk of radon in their own lives. This fact makes it necessary at Stage 2 to counteract biases and encourage people to recognize their own susceptibility to a home radon problem.

To begin understanding the types of biases that run counter to radon awareness, it is worth taking a look at threat identification through the lens of evolutionary psychology. According to psychologists studying human responses to global warming—a topic that has continually struggled with low public salience—certain problems, thanks to their inherent nature, do not trigger feelings of threat despite posing a serious risk to people. Harvard professor Daniel Gilbert provides the explanation for radon’s low salience with an acronym he developed for explaining global warming: PAIN. Standing for “personal”, “abrupt”, “immoral” and “now”, the acronym summarizes the psychological shortcuts humans deploy when deciding what is worth worrying about in a world quite full of potential worries (Gilbert *in* Marshall, 2014). The first and most critical part of accepting the reality of a threat is related to the way that humans are more sensitive to threats that come from other humans, or “personal” threats. Radon, seeping up from the ground, has no anthropogenic ties. To provide an example for contrast, the toxic chemical DDT galvanized huge public action in the 1960s as it could be tied back to a few large industries

that were driven by human motives of profit (NRDC, 2013). Radon comes with no scapegoat, no person to sue, and no single agency or industry that has the responsibility to clean it up.

The second part of threat analysis—"abrupt"—refers to how humans pay greater attention to problems that happen suddenly. There is always a background level of radon, and high concentrations do not occur as a result of some singular event or catastrophic accident. The third threat indicator is "immoral", referring to our sensitivity to threats that run counter to our codes of moral behavior. Related to the example of DDT given already, the desire for profit at the expense of thorough testing and health considerations elicits a moral response in a way radon does not. The final threat indicator is "now," meaning that people give priority to threats that are happening most presently. In the specific case of radon, serious health impacts come after a long latency period and cannot really be guaranteed to come at all.

Dovetailing with basic threat analysis is what psychologists refer to as the "finite pool of worry" (Linville & Fischer, 1991). This refers to people's limited cognitive capacity, something which makes it important for humans to both prioritize and discount certain threats so they can tackle the most important of them. The PAIN acronym is an example of how threats can be organized within the finite pool of worry and, in the case of radon, helps us to understand why a known health threat can be so easily dismissed and forgotten. In a world full of things to worry about, a threat with almost zero immediate consequences and lacking other important threat indicators is easy to push aside when being bombarded with information about other, more salient threats.

Another important cognitive bias that is important for radon's low salience is the optimism bias. This frequently studied bias is one that encourages people to underestimate their vulnerability to a particular threat. Although people find it easy to understand that a threat is dangerous to other people and at a later date down the road, humans tend to strongly discount threats as being serious to their current selves (Weinstein, Sandman, & Roberts, 1990 *in* Hill, Butterfield, & Larsson, 2006). In the case of radon, it is far easier to understand the risk radon poses to others than to ourselves.

Given the cognitive biases that work against radon saliency, it is understandable that outreach materials frequently turn towards fear appeals in an attempt to increase feelings of threat. The link between fear and threat salience has long been supported and studied, and as Weinstein et al. (1998) find, "radon testing behaviors have been positively associated with risk perception of

exposure" (in Hill, Butterfield, & Larsson, 2006). Interest in testing is associated with taking the risk seriously, meaning threats using fear appeals are important in order to counteract radon's threat perception problems (e.g. PAIN indicators).

Although inspiring fear may seem like a simple solution for radon's salience issues, research cautions that there may be an optimal level of fear: too much fear can lead to emotional numbing and too little does not promote a great enough sense of threat for a response. LaTour & Tanner (2003) explain this phenomenon with the idea of a threshold between creating tension and energy for action with a fear appeal, and creating tension that leads to unproductive anxiety.

As Hunt et al. (1995) indicate in their Ordered Protection Motivation Model, productive fear (e.g. below the anxiety threshold) dissipates when people do not receive enough (or adequate) information about coping with a particular threat. Fear is actually found to decrease due to maladaptive coping responses—triggered essentially by a hopelessness when thinking of a problem—that come into play because of strong fear appeals that do not highlight coping information. As LaTour & Tanner (2003) write, the goal of effective radon outreach materials is to instill a degree of tension where individuals understand the threat, but not so much that they feel paralyzed by fear or their inability to deal with the issue and help themselves. The ideal state is a "can-do" attitude where individuals are motivated to protect themselves from radon.

Tanner et al. (1991) posit similar theories about the importance of efficacy when using fear appeals. Using the Ordered Protection Motivation theory, Tanner et al. focus on four critical parts of a threat: the probability of a threat, the severity of the threat, the efficacy of a coping response, and the feelings of self-efficacy for the individual faced with the threat (1991). Effective fear appeals have threat information that precedes coping information, but also presents information relevant to all four parts of a threat (LaTour & Tanner, 2003).

For most cases concerning basic radon awareness, "the coping response is to simply make a phone call, so self-efficacy should be high…" (LaTour & Tanner, 2003). Given that mitigation is often expensive, it is more important for promoting feelings of efficacy to highlight that testing is cheap and easy to do. Furthermore, Sandman & Weinstein (1993) indicate that talking about mitigation costs in outreach can reduce the perception of agency; in turn, this factors into our decision to highlight efficacy at the early stages of radon awareness by helping people find sources of information and understand that testing is easy to carry out. Other factors that may limit efficacy are low income and lack of ownership of one's home, as "significant positive

associations were found for both household income...and homeownership" in testing for radon (Hill, Butterfield, & Larsson, 2006). This is important to consider when creating outreach for the Vermont population which includes a significant amount of low-income individuals and renters. Our approach highlights what is possible, easy, cheap, and effective, rather than what isn't.

One method of outreach recommended by Sandman & Weinstein is "this means you" messaging, targeted at specific regions or populations. The premise of this approach is that telling people about health risks is less important than having them recognize their own risk firsthand. In our case, we used Vermont as a more specific target "region", and talked about local rather than national statistics and risk, as recommended by AARST (2014). Additionally, we suggest the approach of developing outreach materials targeted for specific counties, towns, or zip codes within Vermont. An approach of zip-code-specific mailings was suggested by Sandman and Weinstein. As for specific target populations, we identified five distinct audiences to whom our outreach materials were tailored (elaborated on later). Once individuals "have been provided with general knowledge of their risk, they need to make the link to their own vulnerability" (Sandman & Weinstein, 1993). This links back to the issue of efficacy, but rather than the ability to take action against radon, "this means you" messaging allows individuals identify themselves as vulnerable. This is more effective than having someone else tell you that you are vulnerable.

While it is important to remain credible, emotional messaging should not be eliminated from the discourse on radon in favor of purely scientific and neutral information. Indeed, emotion can be a powerful tool in motivating individuals to act (Sandman & Weinstein, 1993). This is one of the main distinctions of Stage 2 messaging. At this stage, an individual has a base knowledge of radon risks, and is aware that people they know are concerned with or are negatively impacted by radon, but until that individual has a personal response to the information, they will be unlikely to test their home. Hill, Butterfield, and Larsson confirm this trend, stating that "education level and knowledge variables associated with radon were not reliably associated with home testing, although the correlations were in the direction expected" (Hill, Butterfield, & Larsson, 2006). It's not just about education; people need to feel personally implicated in the radon threat. In order to drive home the issue, AARST recommends highlighting "the loss or harm that can result from inaction, such as negative effect on property values, cancer and death" (2014). There is a delicate line between a serious issue and a daunting one, and it is important to

not make the radon issue seem hopeless. We therefore utilized more positive emotions, such as affection for one's child, a sense of belonging to one's community, or the peace of mind in knowing the air you breathe is safe, to counterbalance fear appeals and to motivate radon testing.

Vermont Audience

This general research was applied specifically to the Vermont audience. Vermonters have particular values and sociocultural dynamics, which were taken into account to make our materials relevant and appealing to this target audience.

Vermont is a predominantly rural state with a deep heritage of farming and working with the land. In a report on Vermonters' values and concerns conducted by the Council on the Future of Vermont, respondents placed the greatest value on the state's working landscape and heritage (Moser, Hyman, & Schmidt, 2008). This working connection to the land requires a rural lifestyle, and sure enough the small population of 626,000 (U.S. Census Bureau, 2014) is fairly dispersed across the state, with an average of 67.9 persons per square mile (U.S. Census Bureau, 2010). Rural communities are also a large source of identity for Vermont residents, who "express immense pride in the small scale of community life, the strength of neighborliness, accessibility to government, and the ability to influence changes as individuals" (Council on the Future of Vermont, 2009). However, rural communities are also more vulnerable to environmental health risks such as radon (Hill, Butterfield, & Larsson, 2006). Education is a large barrier when considering different health risks and how they apply to the Vermont population. Additionally, rural families often "suffer from limitations in human capital and environmental resources for which education and access to health care are empirical indicators, respectively." (Leight, 2003, in Hill, Butterfield, & Larsson, 2006).

In rural communities, Hill, Butterfield, and Larsson emphasize the importance of "'insider' leadership to implement an environmental health agenda." These insiders should be "trusted voices from whom information that may not be considered "agenda neutral" can be delivered in a culturally sensitive manner" (Hill, Butterfield, & Larsson, 2006). In Vermont, this notion of "insiders" versus "outsiders" is particularly salient, and "citizens often classify themselves as 'Vermonters' or 'newcomers' (Council on the Future of Vermont, 2009). There is cultural capital attached to the multi-generational Vermonter, though even so-called newcomers may have lived in Vermont for an extensive period and have a strong connection to the state and its issues. We

want to partner with trusted “insider” individuals from within the Vermont community as much as possible in disseminating information about radon, and understand that this dissemination may be most salient through local newspapers, school newsletters, word-of-mouth outreach, or town hall meetings. This informed our decision to partner with local schools within communities (Education subgroup) and create a narrative with accounts from Vermonters personally tied to the issue of radon to be published in local newspapers (Narrative subgroup). Additionally, we believe emphasizing our link to trusted “inside” organizations such as the Vermont Department of Health and local radon mitigators will increase Vermonters’ receptiveness to our campaign.

Because Vermonters organize and identify at the state level, and particularly at the community level, a broad informational campaign or warning against radon levels may not seem pertinent to the average Vermonter unless it is targeted toward them. Thus, we emphasized state or county statistics rather than national statistics, and communicated radon as a Vermont issue, or a local community issue, to help individuals personally identify with this risk. This is especially important given the spatial variation in radon levels throughout the state. Vermont residents derive pride from living in or being from Vermont, and they also value Vermont’s “spirit of independence” (Moser, Hyman, & Schmidt, 2008). In order to cater to these values, we focused on the individual’s right to know about radon, and their efficacy in testing for and mitigating radon. Radon testing should not come across as a top-down mandate, but rather a choice that individuals can make to protect themselves and their community.

Vermonters feel strongly about their natural environment “—particularly its mountains, waters, and weather— [which] appeals to the heart and soul of its citizens. People in this state constantly describe their love for the special place in which they live” (Council on the Future of Vermont, 2009). There is a desire to maintain Vermont’s pristine beauty, and a general opposition to natural resource depletion and over-development, because “significant changes in the environment would damage what many say is most essential to the state and the reason they choose to live here” (Council on the Future of Vermont, 2009). Vermont is viewed as a “green” state, with few visible environmental threats— no urban smog, no chemical plants dumping toxins, etc. Thus, Vermonters may subconsciously view themselves as being immune to environmental threats. Radon is a natural product of the radioactive decay of uranium, a naturally occurring element found in varied amounts in rocks, sediments and soils. What this means is that

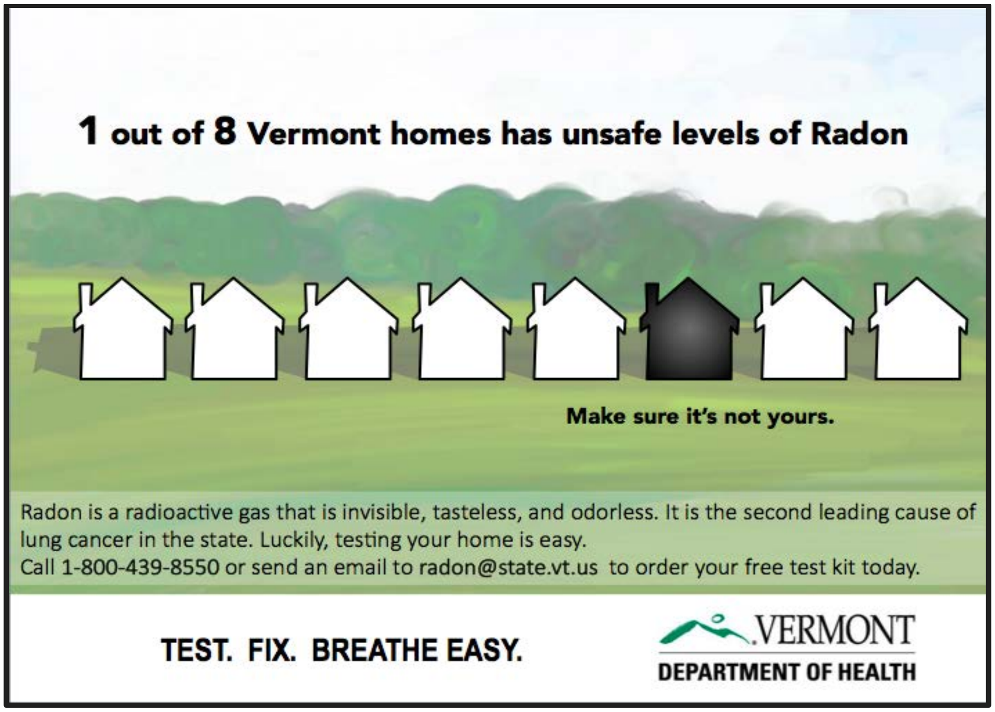
a beautiful “pristine” landscape could emit dangerous amounts of radon into the surrounding air without any physical indication that this area is “unsafe” for humans.

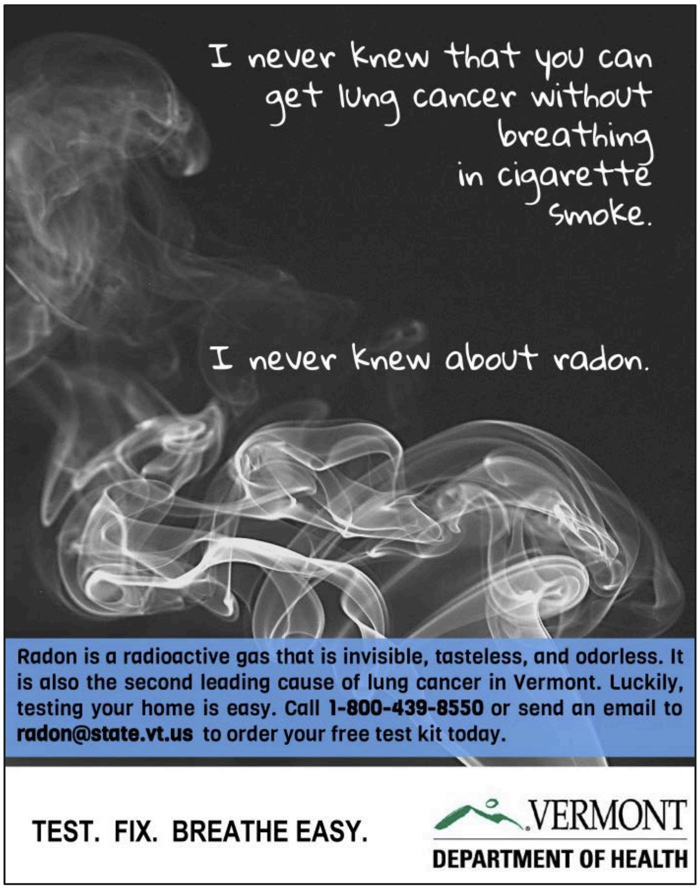
Target Audiences

Based on the target groups outlined by our community partner at the Vermont Department of Health, we identified five target audiences for our outreach materials. We created materials tailored to each one of these target audiences, taking into consideration which approaches may be more effective for each of them.

1) General Vermonters

We decided to treat the state audience as distinct from the wider national audience and prepared Vermont-specific materials. Although this may not seem like a particularly “targeted” audience, we decided that materials designed generally for Vermonters were important for a broad reach within the state. We utilized Vermont radon statistics, as suggested by AARST (2014), to increase people’s sense of identification with the problem and, therefore, their vulnerability. We provided comprehensive information about radon assuming that the general population is at stage 0 or 1 for awareness given that approximately 10% of Vermont homes have been tested (VDH). In addition to more general information about radon, we also provided information about how to obtain more information and request a free test kit to encourage feelings of efficacy. We created a print ad (see below) and video (link provided below) for this general Vermont audience.


1 out of 8 Vermont homes has unsafe levels of Radon
Make sure it's not yours.
Radon is a radioactive gas that is invisible, tasteless, and odorless. It is the second leading cause of lung cancer in the state. Luckily, testing your home is easy.
Call 1-800-439-8550 or send an email to radon@state.vt.us to order your free test kit today.
TEST. FIX. BREATHE EASY.
VERMONT
DEPARTMENT OF HEALTH


I never knew that you can get lung cancer without breathing in cigarette smoke.
I never knew about radon.
Radon is a radioactive gas that is invisible, tasteless, and odorless. It is also the second leading cause of lung cancer in Vermont. Luckily, testing your home is easy. Call 1-800-439-8550 or send an email to radon@state.vt.us to order your free test kit today.
TEST. FIX. BREATHE EASY.
VERMONT
DEPARTMENT OF HEALTH

“Doodle” video: Credit goes to Middlebury student Daniel Andrada for filming and editing the video.

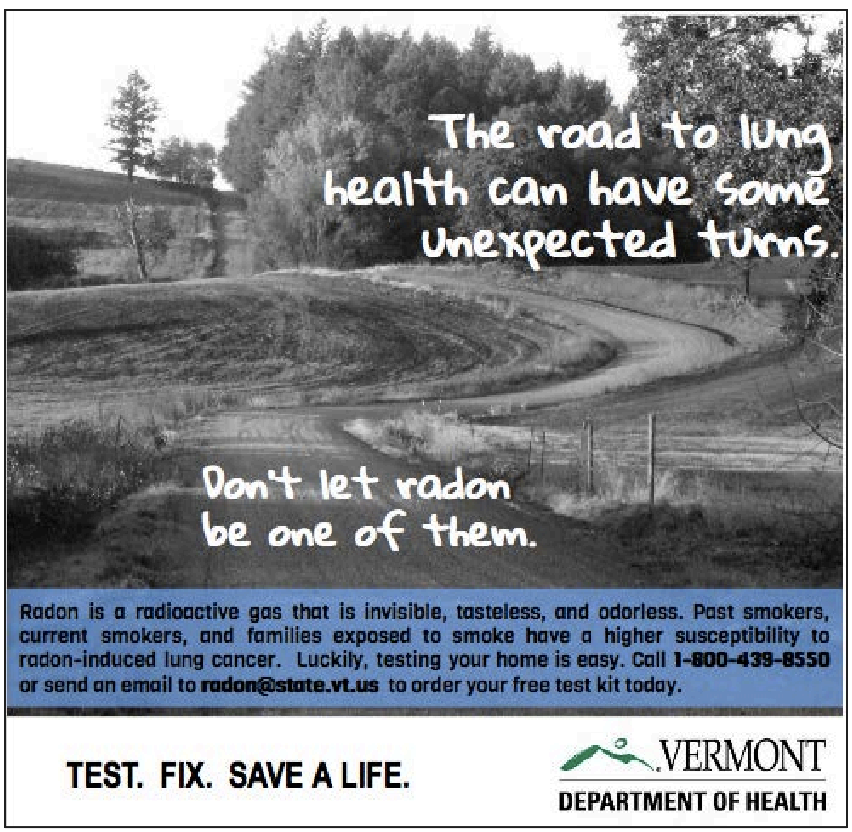
Youtube video link: https://www.youtube.com/watch?v=pPziSJm2jvs

Downloadable video file:

https://drive.google.com/folderview?id=0BwD9aHufnjl5fjJuSkx4SWZYUVpERlkyU1R3U29HWjFfd1FKWl81MFdMWHFDeHdhTWw2VkU&usp=sharing

2) Smokers who are trying to quit or have already quit

We identified smokers as a particularly vulnerable audience given the negative synergistic effect of radon and smoking on lung health. Our goal was to develop materials that will appeal personally and emotionally to smokers to protect their health as well the health of those close to them that are at risk of second-hand smoke exposure.



3) Parents or new parents

We identified parents or new parents as a good target audience given that research indicates that children may be particularly vulnerable to radon (Hill, Butterfield, & Larsson, 2006). Hill, Butterfield and Larsson (2006) write, “When adjusted for size, children have a greater body surface area, breathe more air, consume more food and fluids, and metabolize toxins differently than adults. In addition, developmental behaviors such as placing unclean objects in their mouths, spending large amounts of time on floor surfaces, or being held in close proximity to lit cigarettes place children at additional risk for exposures to environmental toxins.” Additionally, we identified this target audience given that parents may respond more to radon outreach directed at protecting their children’s health rather than at their own. As Latour and Tanner (2003) write, “[H]aving children is a significant mediator of the threat.”

To address this audience, we appealed to parents’ feelings of responsibility towards and affection for their children. We decided to use comparable risks (see literature review) that would be particularly relevant to parents with children while also providing the basic information and efficacy-enhancing information as with our other materials.

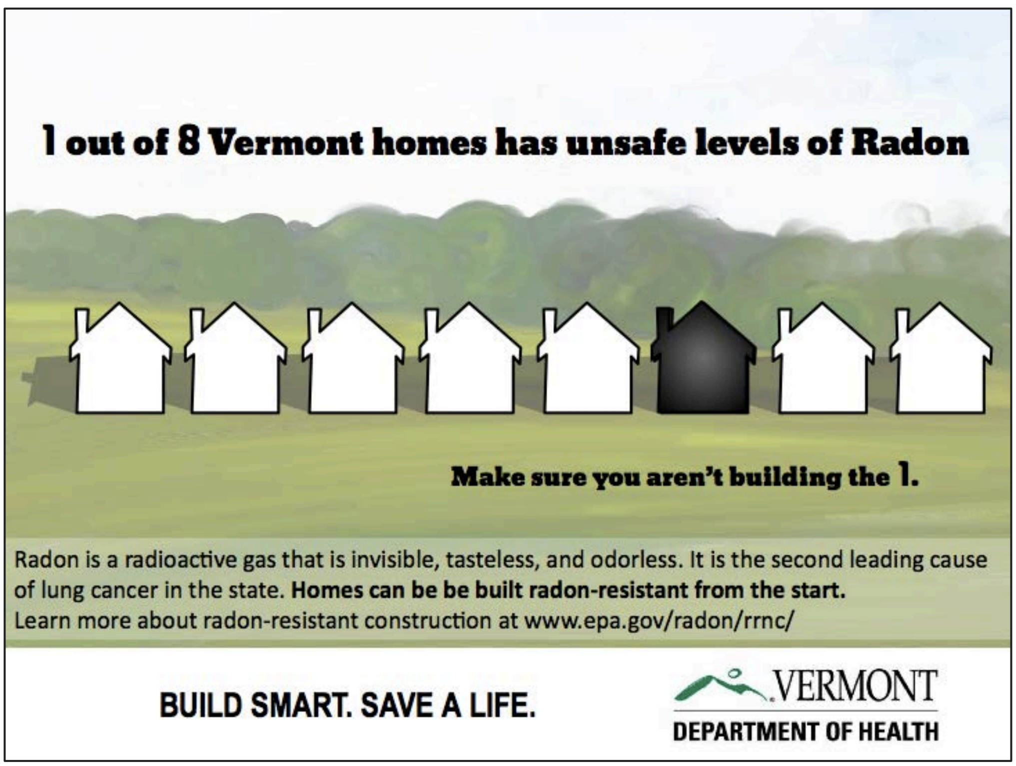
Did you know?
1 out of 8 Vermont homes has unsafe levels of Radon.
Take steps for your child's health today. Test your home for radon.
Radon is a radioactive gas that is invisible, tasteless, and odorless. It is the second leading cause of lung cancer in the state. Luckily, testing your home is easy.
Call 1-800-439-8550 or send an email to radon@state.vt.us to order your free test kit today.
TEST. FIX. BREATHE EASY.
VERMONT
DEPARTMENT OF HEALTH

We spend a lot of time keeping kids safe.
Don't let radon slip under your radar.
Radon is a radioactive gas that is invisible, tasteless, and odorless. It is the second leading cause of lung cancer in the state. Luckily, testing your home is easy.
Call 1-800-439-8550 or send an email to radon@state.vt.us to order your free test kit today.
TEST. FIX. BREATHE EASY.
VERMONT
DEPARTMENT OF HEALTH

4) Construction professionals

We identified construction professionals as an important group to target given that they have the ability to reduce the amount of homes containing unsafe radon levels. Pre-emptive radon-resistant new construction is far cheaper and easier than retroactive radon mitigation. The goal of these outreach materials is to inform construction professionals about the health risks of radon and the important role that they can play in reducing these risks. To raise their efficacy, we give clear direction for them to look at the EPA's guidelines on radon-resistant new construction. The materials appeal to both their conscience and the desire to be competitive in their industry, as radon-resistant homes may have a higher value among concerned buyers.

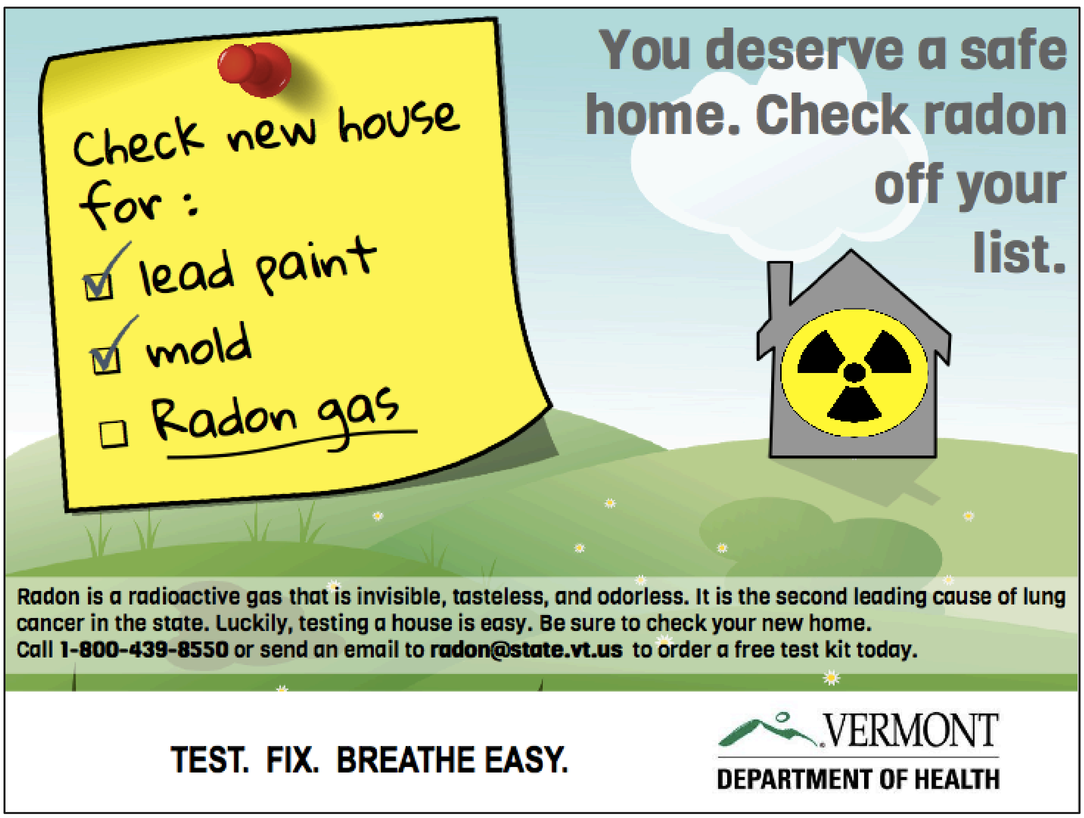
IT'S EASY TO BE
A HERO.
help build
radon-resistant
homes & healthy futures
Radon is a radioactive gas that is invisible, tasteless, and odorless. It is the second leading cause of lung cancer in the state. Homes can be be built radon-resistant from the start.
Learn more about radon-resistant construction at www.epa.gov/radon/rrnc/
BUILD SMART. SAVE A LIFE.
VERMONT
DEPARTMENT OF HEALTH



1 out of 8 Vermont homes has unsafe levels of Radon
Make sure you aren't building the 1.
Radon is a radioactive gas that is invisible, tasteless, and odorless. It is the second leading cause of lung cancer in the state. Homes can be be built radon-resistant from the start.
Learn more about radon-resistant construction at www.epa.gov/radon/rrnc/
BUILD SMART. SAVE A LIFE.
VERMONT
DEPARTMENT OF HEALTH

5) Renters and Homebuyers

Renters and homebuyers were identified as an important audience to target given that Sandman & Weinstein (1993) suggest that new homeowners are more receptive to testing than people who have been living in the same home for a long time. Health issues are frequently considered and tested for before buying or moving into a new home, so targeting a group that is aware of risks and thinking of vulnerabilities is ideal for effectively raising testing numbers. Renters are a unique audience in that they don't have much control over modifying their living space, but we included them in our materials as they may have some of the same concerns as homebuyers when it comes to moving. We decided to emphasize that these target groups have the right to know about potential risks in their living space. At the time of this report, there is no legal obligation for homes to be tested, so we need to instill a personal motivation within renters and homebuyers to defend their right to breathe safe air.



A note on outreach materials:

The materials produced for this project were made in Google Slides, and the link to these materials is attached below. Keeping the materials in this form allows for any of them to be edited and modified to better suit the VDH's needs. Understanding that these are not image files, we recommend that the best method for converting these to images that can be used for printed advertisements is to save them as screenshots. We have encountered issues with shifting/misalignment in our visuals when they were presented without being saved as a screenshot first, and we therefore recommend this as the best way to convert these into files that can be used for presentation and print purposes. All computers have a screenshot function so we do not foresee this as a problem for the VDH or ALA's use of these materials.

Additionally, all images used in these materials are either creative commons images that can be used, edited, and distributed for non-commercial purposes, images that need simple attribution (attributions are included in the current materials), or images that have been purchased for distribution rights (baby and cactus image).

Link to editable outreach materials:

https://docs.google.com/presentation/d/1if-mzRrN3ZDJJg-YejFWOnx7WSP3Kfjp9DDDEwNszCg/edit?usp=sharing

Narrative

The article we drafted (Appendix C) aims to bring attention to the importance of testing for and mitigating radon in Vermont by reaching the state's wide newspaper audience in one swoop with this credible, impactful medium of local information dissemination. We decided to focus our efforts on creating a written narrative based on the real experiences of people in the community in order to highlight the urgent relevance of the issue to all Vermonters and increase its salience in their minds. We incorporated the research team's findings about effective communication and the significance of "social proof" into our writing. We have learned that there needs to be a balance of threat and practical steps for mitigation as well as urgency and hope. We hope that hearing local accounts of radon testing, mitigation, and health risk will motivate people to take action by testing their private and public buildings and investing in the

mitigation of any detected risk. We also expect that the lived experiences of a Vermonter with possibly radon-induced lung cancer featured in our narrative will inform the policy group's proposals and hopefully even any legislation that is passed in favor of mandatory testing and mitigation.

Our narrative opens with a Vermonter's story, grabbing the readers' attention by introducing the unexpected hazard posed by radon with her true account of developing lung cancer despite being a nonsmoker. We will weave in an overview of facts about radon in general and the problem in Vermont specifically. Our goal is not to frighten or repel readers with doom and gloom facts about the deadliness of radon and the need to test and mitigate. Instead, we hope to convey the optimistic, comforting message that although it presents a serious health risk—as this Vermonter's case illustrates—radon can be navigated and reduced with concern, initiative, collaboration, and determination, ensuring a healthier future for ourselves and upcoming generations. We hope the VDH finds it useful for their media and press outreach.

Education

Although the narrative piece will be accessible to a large audience of adults, we chose to target some of Vermont's younger populations as well. Our final approach to increasing saliency of radon in Vermont was to establish a long-lasting, community-based education program. Utilizing key research on environmental education and service learning projects to justify our decisions, we compiled resources that can easily be taught in any Vermont middle, or even upper elementary, school. While creating this program, we wanted to keep our four main goals in mind: (1) to establish a sustainable model with an easily replicable template; (2) to establish connections in Vermont communities where high school students return to their middle schools and give back to younger generations and the institutions that promoted their education; (3) to help high school students reach their required community service hours; and (4) to increase awareness for radon as an environmental health risk by both middle and high school students sharing what they have learned with their parents and for the adults to then test and mitigate against radon in their homes.

Environmental education aims to inform people about how natural environments work with the expectation that increased knowledge and awareness of environmental issues will inspire behavioral change. Environmental education is typically provided to children and young adults.

It is an interdisciplinary field consisting of outdoor activities (“Hands On, Feet Wet” philosophy), science projects, art and music, games, and storytelling. Introducing youth to this type of education is essential as beliefs about the environment develop at an early age and, once established, are not easily changed (Damerell et al. 2013). Environmental education has proven successful in shaping these beliefs in favor of the environment. For example, in a study by Damerell et al. (2013), researchers found that children who attended a wildlife club and were taught about wetlands demonstrated significantly increased knowledge and understanding of that type of ecosystem after completing the program. Therefore, children appear to be receptive to information provided to them in an environmental education setting and it has a positive influence on their understanding of environmental issues.

But what role can the education of school children play in the mitigation of radon? Children are not homeowners and ultimately will not be making major decisions in their household. Serious environmental issues, like radon, require swift action and legislative change, but the middle and high school students we would like to educate will be incapable of implementing this type of change, at least in the immediate future. The great thing about kids is that they love to share, especially when something new and exciting happens. Hands-on and engaging activities are best for capturing the children’s interest, and interested children are much more likely to share what they have learned with parents and friends (Damerell et al. 2013, Duvall & Zint 2007). In this respect, kids can be a great tool in motivating thought and behavior change in their parents. Parents with children who study environmental issues also have significantly higher understanding of the same issues (Damerell et al. 2013). Interestingly, parents are also unaware that they are gaining their knowledge about environmental issues from their children, thereby maintaining autonomy in making behavioral changes. The study by Damerell et al. (2013) demonstrated that parental behaviors were influenced by the knowledge learned through their children. Parents who had children in wetland programs also consumed significantly less water in their households. The results strongly suggest that children are effective agents for change, at least in the immediate family, which may be essential for motivating their parents to test for radon in the home.

One essential way to encourage intergenerational learning in environmental education is with take-home projects (Duvall & Zint 2007, Mandel 2013). Parents are more likely to increase their own understanding of a topic when they are asked to engage directly with their child.

Shared homework activities were found to increase parental knowledge by 38% whereas control groups show no parental knowledge improvement in the topics discussed (Damerell et al. 2013).

Another essential aspect of intergenerational environmental education is a focus on local community issues. Overall, when the children can see what they are learning about right outside their front doors, they are more likely to accept ownership of their local environment. It also encourages them to make strides towards changing behaviors in order to be more congruent with their thoughts about the environment (Duvall & Zint 2007). When placed in a community context, parents are also more likely to listen and learn from their children and then share that information with neighbors (Mandel 2013). Ultimately, our project needs to remain focused on Vermont, and possibly even more specifically to the town level, and include direct interaction with parents in order to promote understanding in future generations of Vermont homeowners, changed behavior in current Vermont homeowners, and the sharing of knowledge amongst peers and neighbors.

Service learning is another helpful tool for the promotion of individual learning and character development. Typically, service learning is supported because it helps students become active members in the community, meets any needs that the community might desperately have, and encourages altruism. Although service learning projects are not fully understood by the general public, they are widely supported by both parents and teachers as a benefit to the individual students and the community at large (Biling 2000). We chose to make our education program a service learning one as "learning occurs best when students are actively involved in their own learning and when that learning has a distinct purpose" (Biling 2000 p. 659). We anticipate that high school students will greatly benefit from teaching younger students by experiencing a sense of contributing positively to their community while also improving their own understanding of the dangers of radon. Hopefully both outcomes will influence them as they enter adulthood and begin to think about lives outside of their parents homes where the decision to test and mitigate against radon may be their own.

In light of this research, the education component of the saliency team's efforts involve lesson plans developed so that high school students can teach middle school students. On a more personal and anecdotal level, each member of the saliency team clearly remembers the issues and lessons that were taught to them by older students they respected. These experiences, coupled with our findings on research-based effectiveness, inspired us to create our own educational

outreach program for radon. After contacting the National Radon Hotline, we were directed to several educational materials that the National Radon Program has already created and styled in lesson plan format, complete with notes for the teacher. Out of ten possible lessons, we chose four that we felt are distinct and viable options for teachers to select based upon their time constraints, resources, and capabilities. We have affectionately named our education program ***Radon Rebels***.

The lesson plan begins with a short overview of what radon is, and then proceeds to ask students to engage their new knowledge in some sort of activity. Two of the activities are a one-time lesson, while the other two involve a take-home activity to be discussed the following day, or at some other time shortly following. Of the two in-class activities, one asks the students to draw a picture of their own home and identify areas where radon might be coming into their house. Students are then presented with different methods of mitigation, and asked which might be most effective. The other one-time activity asks students to conceptualize what it means to find something that remains unseen and recognize its effects. The students are given a clay ball with something (e.g. a toothpick, a magnet, etc.) inside that they must discover by applying different detectors and tools. The lesson unfolds to discuss the different ways that radon is detected in homes and the importance of test kits, and also addresses radioactive decay and its effects on the lungs.

The second two activities are more in-depth and requires a more extensive teaching commitment. One lesson plan is also centered on mitigation and provides an opportunity for students to not only explore mitigation strategies, but also to understand the process of radon build-up in homes. Specifically, students will use a smoke experiment to emulate the Bernoulli Principle, as well as simple convection currents, to demonstrate how radon moves into a home based on temperature differentials in the building and/ or changes in the inside and outside air pressures.

The second take-home activity is focused on what people know about radon and requires students to conduct a small survey of five people in their community. The survey asks simple yes or no questions, such as if they think radon is a health hazard, if they feel it can be easily tested for or removed, and if they know where radon comes from. Surveys can provide useful and current information about people's opinions and knowledge about important issues such as air pollution, voter preferences, and, in this case, radon gas. The radon survey used in this

investigation can be used to introduce students to radon while simultaneously reinforcing important learning process skills including data collection, tabulation, and graphing. Examples of all lesson plans are provided in Appendix D.

In light of these selected lesson plans, we designed their implementation to establish a sustainable, replicable, and engaging model to be started and continued after our graduation in May 2015. To achieve this, we reached out to various high schools in nearby areas that require their upper class students to complete community service hours as part of their graduation criteria. Our aim was to teach high school students the material, and then connect them with their local middle schools to educate them while earning their hours. When the senior high school students graduate, there will be upcoming seniors to continue the program in both the education of younger students and the introduction of the program to new underclassman who will be seniors after them (Figure 3.1). At the very least, even if the education of middle schoolers does not affect their parents, we will be bringing up a young generation of Vermonters that is aware of what radon is and how its adverse effects can be prevented.

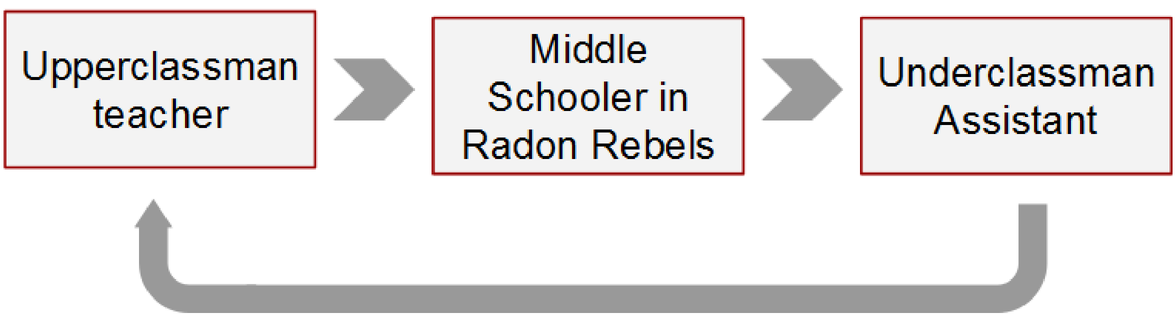


Figure 3.1. Radon Rebels sustainability model. The upperclassman teacher is a high school junior or senior.

We originally planned to have our program implemented by the end of the semester, but after communicating with several contacts we have determined that our program will be more effective and better fit into the structure of the interested schools if it were to be implemented at the beginning of the school year as opposed to the end. We connected with Montpelier High School's community service director, Matthew McLane, who was enthusiastic about our idea and is happy to plug in and support our efforts. He reached out to two science teachers to direct their students to our program, and he also reached out to the principle of Montpelier Middle

School for her input. We also contacted Margaret Dulli, who is the liaison between Vermont healthcare and educational institutions. She put us in contact with the Assistant Superintendent of the Rutland County school district, Rob Bliss, for whom we created a flyer to be distributed to those he thinks will be receptive (Appendix D). We have also been in correspondence with a junior at Rutland High School interested in teaching the materials. We hope to continue this relationship and have her generate interest in her peers to establish a solid group of students willing to implement the program at the beginning of next fall. If we have a committed group of high schoolers and a receptive middle school class for next year, we feel confident that we have succeeded with our intention.

Conclusion

In order to increase awareness about radon in Vermont, we created an array of education and outreach materials that focus on radon's health risks and encourage people to test their homes and schools. We also created a narrative account of radon's effects on a local community member to make the issue more salient and personal. We intend for these materials to be transmitted through a number of local organizations: the outreach materials can be used and distributed by the Vermont Department of Health and/or the American Lung Association, the lesson plans can be implemented by a number of local middle and high schools, and the narrative piece can be published by various local newspapers or news outlets. Our intent is that by dispersing a range of materials through a variety of outlets, we will be able to reach a wide audience of Vermonters with different levels of radon awareness. We suggest that the research we compiled on effective radon outreach be utilized by the Vermont Department of Health to inform their future work.

Chapter 4. Policy

Executive Summary

Radon, a naturally occurring airborne carcinogen, is the second leading cause of lung cancer in the United States. It is responsible for an estimated 50 deaths from lung cancer per year in Vermont, nearly three times the number of deaths caused by drunk driving (Grass, 2015; MADD, 2014). While mitigating exposure to high levels of radon is relatively simple, the state of Vermont has neglected to implement any policy addressing this public health issue. The average annual yearly cost of lung cancer treatment in 2015, adjusted for inflation, is $78,668 per patient (Cipriano et al., 2011). By avoiding the approximately 58 cases of lung cancer attributable to radon exposure, the state of Vermont stands to save $4.56 M annually to the healthcare system (Appendix E.1 and E.2).

After a thorough review of other states' policies and engaging with relevant stakeholders, we recommend that Vermont legislators take the following low-cost, high-impact policy action steps to address the issue of radon contamination in Vermont:

1. Maintain VDH's current radon budget and appropriate funding for select radon programs including free test kits, reprioritizing advertising mediums according to risk criteria, establishing partnerships, and supporting radon education programs as part of schools' existing community service requirements.
2. Require testing in all public Vermont school buildings and disclosure of the results.
3. Direct local zoning boards to adopt radon-resistant new construction (RRNC) into building codes.
4. Require testing in all rented residential buildings and disclosure of the results.
5. Require testing in all private business establishments and disclosure of the results.
6. Require the provision of Vermont-relevant VDH materials about radon during real estate transactions.
7. Require disclosure of radon testing history of private homes during point of sale.
8. Require that individuals performing radon testing and mitigation services acquire a certification from the American Association of Radon Scientists and Technologists (AARST).
9. Require a state-maintained public directory of AARST-certified radon professionals.

Introduction

Radon

Radon is a naturally occurring radioactive gas produced by the decay of uranium. It diffuses through bedrock and soil to accumulate inside homes and other structures. As radon naturally decays, it releases alpha radiation which is known to cause cancer. It is estimated that exposure to radon is the second leading cause of lung cancer and results in 15,000-20,000 deaths per year in the U.S. (EPA, 2003) The EPA has set an action level of 4.0 picocuries per liter (pCi/L) and homeowners with concentrations above this threshold are encouraged to invest in testing and mitigation measures. However, this action level is not uniformly accepted; for example, WHO recently announced a recommended action level of 2.7 pCi/L (Sethi et al., 2012). There appears to be a linear dose-response relationship between exposure to radon gas and lung-cancer (Appleton, 2007). Therefore, no level of exposure is deemed safe, and all homeowners should be encouraged to test their homes.

Policy Environment

Despite 1 in 8 Vermont homes having radon concentrations above the EPA threshold, a rate that is twice the national average, Vermont has failed to make the issue of radon contamination and radon-induced lung cancer a policy priority (EPA, 2013). Thirty-two other states have adopted some form of airborne radon policy, including every other state in the northeast United States (Figure 4.1).

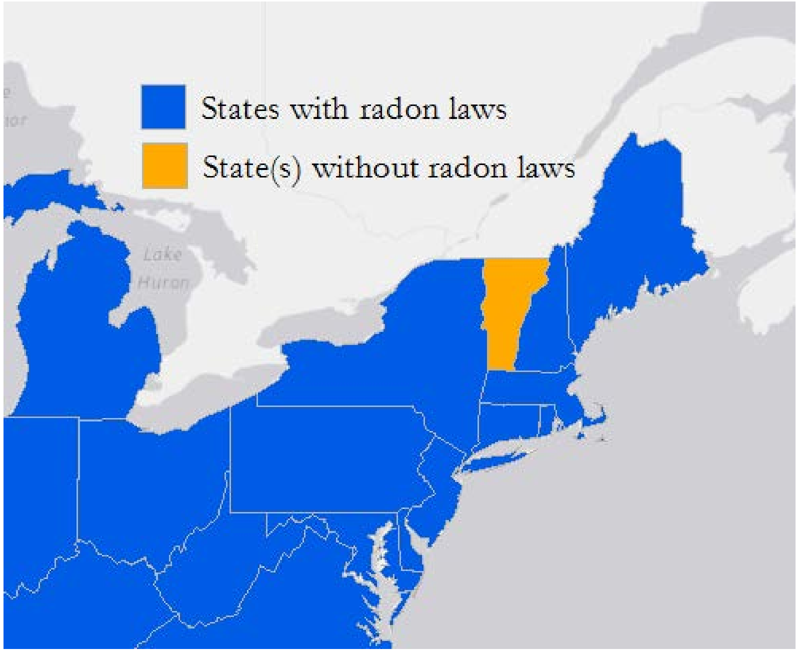


Figure 4.1: Presence of Airborne Radon Laws in the Northeast (as of 2011). *Data from CDC*

Proposed Action

Our goals for this study were twofold: to identify high-priority policy targets in Vermont—buildings where Vermonters spend a significant portion of their time and buildings that house vulnerable populations—and to analyze the options that the legislature could take to address the radon threat in these buildings.

After a thorough review of other states' policies, prior literature, and speaking with relevant stakeholders, we have crafted a suite of policies to address the issue of radon contamination in Vermont. We have organized the suite of actions according to a matrix of feasibility and financial intensity (Figure 4.2). Financial commitment is considered as both direct cost to the state and imposed private costs. Education and outreach are the lowest-cost initiatives and are the only option currently being pursued in Vermont. Increasing in financial requirements are integration into real estate (transaction disclosure, building codes, certification), mandatory testing, and then mandatory mitigation.

Our ultimate recommendations attempt to strike a balance between cost, feasibility, and positive outcomes that characterize successful public health policy. Most of our recommendations will serve to increase the amount of radon testing in Vermont. Only 22% of Vermont's schools and approximately 10% of private homes have been tested for radon, while none of Vermont's seven prisons have ever been tested. The lack of test results makes

developing radon management plans difficult at every scale, from state-wide policies to household decisions. Plus, the lack of testing contributes to radon's lack of salience among Vermonters. Finally, testing is relatively inexpensive compared to mitigation: the most common type of test kits cost $10 each and do not require any specialized knowledge to use. We also make recommendations regarding a licensing program for radon professionals and preventative construction methods in Vermont's building codes.

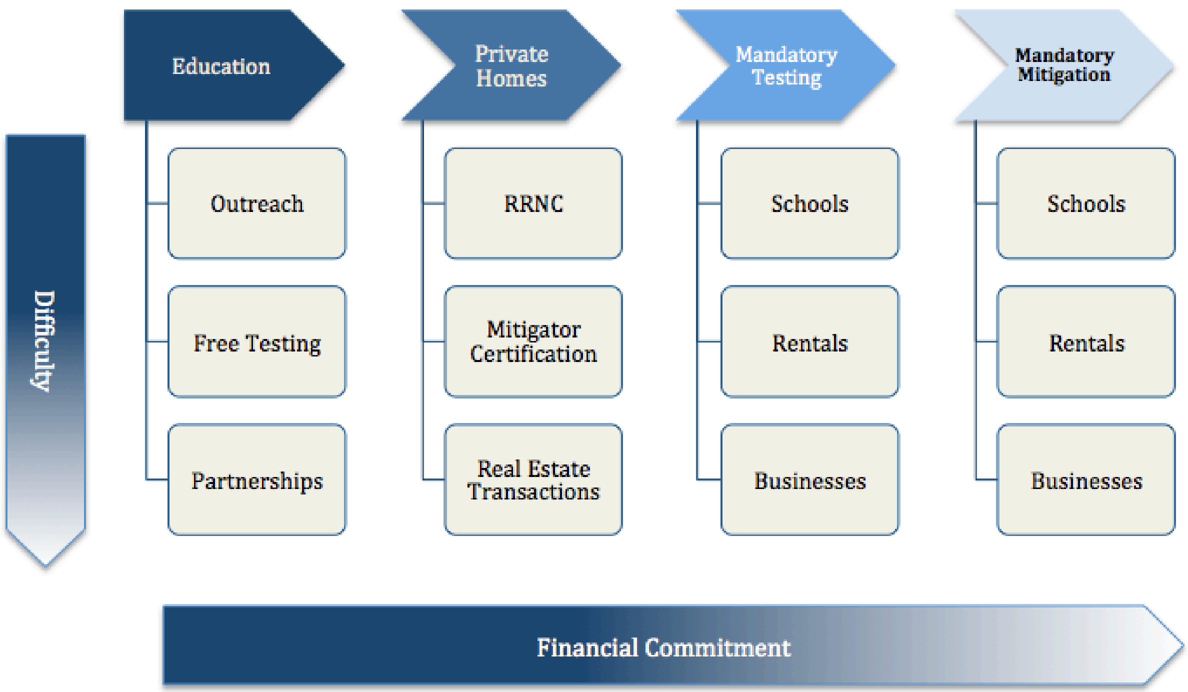


Figure 4.2: Suite of policy options to address radon in Vermont

Education

Overview

The Vermont Department of Health's (VDH) radon program has served as the primary vehicle for radon outreach in Vermont since the creation of its radon program. The VDH program places its main focus on education and the distribution of free testing kits to the general public. The radon program is directly funded through the Indoor Radon Abatement Act of 1988, which authorizes EPA to provide technical and financial assistance through the State Indoor Radon Grant (SIRG) program. This federal support facilitates education, outreach, and provision of free test kits working toward the expressed goal of minimizing and preventing radon-induced

lung cancer deaths. The VDH radon program has a total annual budget of $216,667, of which 60% is provided by EPA and 40% from a state matching fund (SIRG 26, 2015, Table 4.1). Importantly, this budget is contingent upon political approval and thus subject to future fluctuations and/or termination.

Table 4.1. VDH Budget Allocation (7/1/2015 – 6/30/2016) (Grass, 2015)

Item	**Budget**
Personnel	$94,075
Program Technician	*$43,492*
Certified Measurement & Mitigation Specialist	*$40,062*
Fringe Benefits	$37,630
Travel	$3,500
Supplies	$18,766
Other	$6,250
Promotion/Outreach	*$2,500*
Postage for Mailings	*$1,000*
School Mitigation Support	*$2,750*
Total	**$216,667**

VDH has provided over 20,000 long-term test kits to date through its radon program and maintains an active database with their respective results (SIRG 25, 2015). To supplement their provision of free test kits, VDH has embarked on a robust print and radio education campaign to increase knowledge of radon. The VDH utilizes Vermont Public Radio to disseminate radon public service announcements, EPA campaign materials, and VDH contact information. Print outreach, newspaper ads, and press releases all are targeted towards regions with low radon testing rates in order to improve awareness of the free test kit program (SIRG 25, 2015).

Much of the previous activity by private organizations surrounding radon in the state of Vermont was spearheaded by the Vermont Public Interest Research Group (VPIRG) in the 1990s. Throughout the 1990s, VPIRG elected to make radon a priority, launching an outreach program in 1994 with the goal of raising awareness of radon, encouraging legislation, and forming coalitions with construction and real estate groups in Vermont. Additionally, the American Lung Association (ALA) remains a useful potential private partner for funding and outreach efforts. For example, ALA was responsible for sponsoring the VPIRG cooperation with Burlington Electric to include radon information in utility bills. (For a complete list of VPIRG activities, see Appendix E.3; for more information on VDH's current efforts, see Appendix E.4).

Recommendations

We propose bolstering the public outreach program as a baseline effort for radon action in Vermont. We've determined the continuation of current VDH efforts supplemented by a revitalization of select VPIRG strategies to be the most effective program, in terms of balancing public health impact and financial intensity. We suggest that VDH adopt successful VPIRG strategies and remain as the lead organization conducting the campaign. As such, state funding should be diverted to the VDH if or when federal funding fluctuates in order to insulate them from financial uncertainty. A reliable budget stream is vital for VDH to sustain their initiatives and reach underserved demographics.

Budget uncertainty has crippled radon policy in surrounding states. Despite having binding legislation, both Maine and New Hampshire have been unable to track or administer their testing programs due to a lack of financial resources. In fact, Maine radon officer Bob Stilwell reported that their office is unable to properly track or enforce their 2009 law mandating testing in rental properties (Stillwell, 2015). Additionally, budget uncertainty can be detrimental to productivity as the VDH is unable to accurately plan future action.

Therefore, we've determined that maintaining a secure funding stream is the first step to the program's success at any policy commitment level. With the security of their $216,667/year radon budget, VDH will be able to continue to provide free test kits, disseminate educational materials, retain full time employees, and strategically plan for future efforts. As long as federal grants remain in place, this would not present any increase in costs to Vermont. However, we propose a mandate to fill a budget gap, if any is created, with state funds up to a threshold of the current VDH budget.

We maintain that availability of free testing kits is the most crucial offering of the VDH program. Educational outreach materials, media campaigns, and partnerships all hinge on the ability of citizens to quickly acquire test kits for free. Without this offering, it's likely that the cost and effort to purchase your own test kit would be prohibitively high for many citizens, resulting in inaction (Sandman and Weinstein, 1993). In the absence of binding policy, increasing testing remains the top priority to reduce public health risk. Thus, free test kit provision should be maintained as a bare minimum. We estimate this program to cost the state ~$10/test kit including laboratory analysis (Grass, 2015). Given current VDH distribution this

equates to approximately $28,000 between supplies and administrative expenses which require half of a technician's full-time effort (Grass, 2015).

We've identified partnerships as an integral strategy to boost testing rates. While VDH has effectively maintained relationships with public entities such as town health officers, we see the potential for expansion into the commercial arena. VPIRG executed this strategy particularly well with community food stores and utility providers, generating hundreds of tests and calls for information (VPIRG, 1994). Consequently, we recommend a resurrection of partnerships with community outlets and utility companies. Community stores, such as natural food markets and supermarkets, provide high traffic areas and facilitate conversation amongst those who are likely to live within close proximity—both of which are primary drivers for testing (Sandman and Weinstein, 1993).

Additionally, disseminating information through utility bills provides an opportunity to broaden the number and type of resident reached. It is of our opinion that VDH advertising campaigns suffer from reaching a narrow segment of the population—namely those who access public channels. However, utility bills are ubiquitous and demand every homeowners' and/or renters' attention. Therefore, we recommend the VDH seek to reopen partnerships with Vermont utility providers to include radon information in customers' bills with priority given to those serving high-risk areas outlined below. We estimate statewide expansion of partnerships to cost $5-10K, and could be significantly less expensive if sponsorship from ALA is reestablished (VPIRG, 1994).

We see the integration of radon outreach programs into community service programs as an effective strategy to perpetuate education with a revenue neutral model. The VDH and VPIRG have both attempted similar strategies by coupling with school curriculums. (VPIRG, 2014, SIRG 24) However, we suggest taking a unique approach targeting community service. Our peers in the salience group (Chapter 3) have begun partnering with high schools in an effort to get radon education acknowledged as a legitimate source of community service hours. If approved, this would be a cost-free method to encourage education year-after-year. We recommend this initiative be supported by education boards and policy makers within their respective school districts.

Finally, we recommend all education and outreach initiatives be re-prioritized according to geographic risk factors in order to maximize public health benefit per dollar spent. Currently,

outreach efforts are targeted to areas with low testing rates; however, this does not necessarily reflect the most at-risk populations. Therefore, we suggest utilizing data from the geospatial group (Chapter 1) to identify priority areas where there is both a propensity for elevated radon levels and high population density (Figure 4.3).

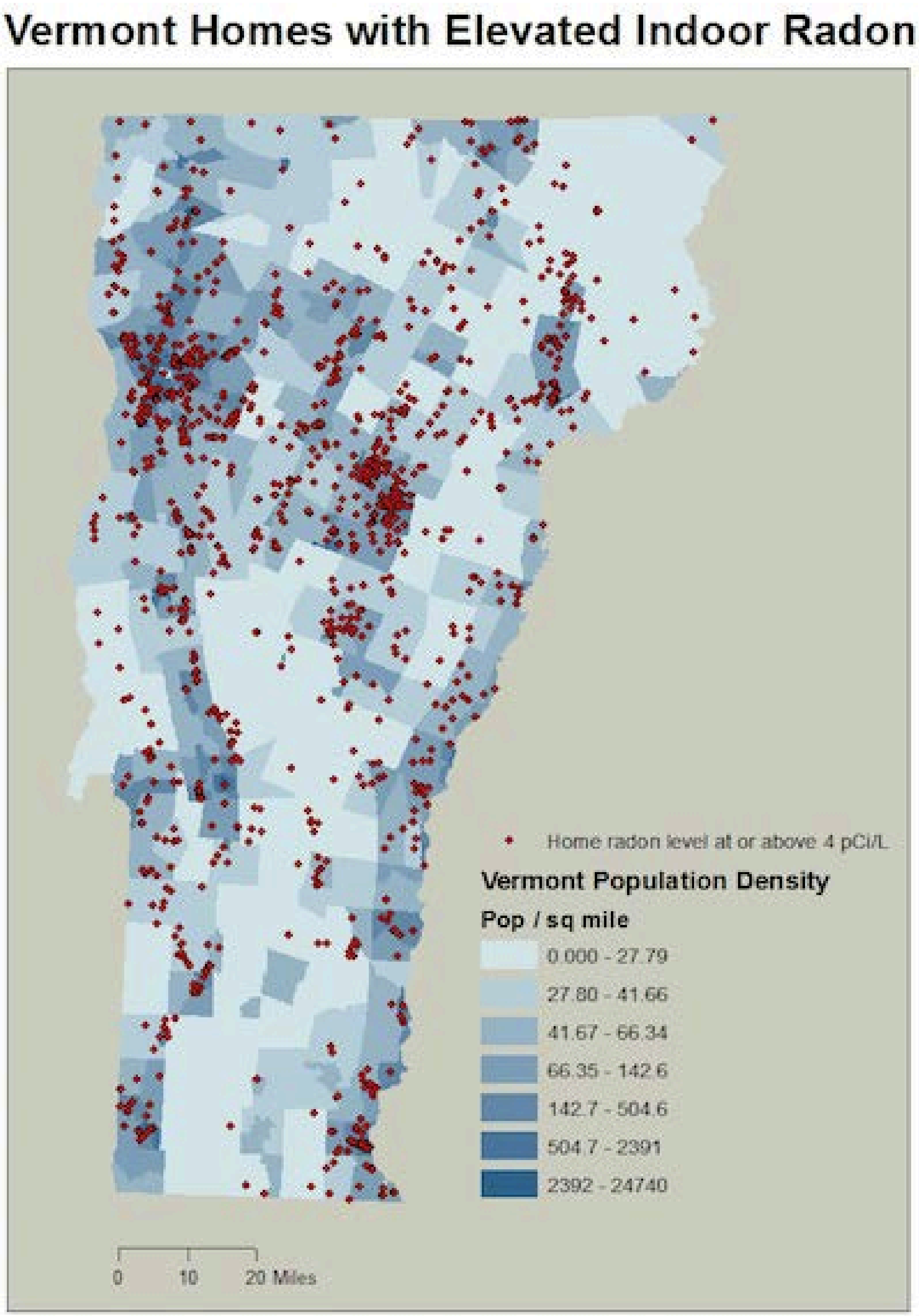


Figure 4.3: High test incidences with population density in Vermont

Funding

Vermont’s radon program requires a stable source of funding for its current outreach efforts to prepare for the potential termination of Vermont’s State Indoor Radon Grant. Additionally, each of our proposed scenarios would require additional funding, whether to assist individuals or organizations that are not financially able to mitigate a detected radon problem or for the purposes of enforcing new laws. This has been a major problem in Maine, which recently passed relatively comprehensive legislation compared to other states. We reached out to Bob Stillwell with Maine’s radon control program. He told us that his department “...received no additional funding to enforce that law, and have since faced severe funding cuts and staff reductions, resulting in the inability to enter the data into a central database, or even track the number of tests received specifically due to that law.” We have identified several potential funding sources based on our research and our conversations with various interested parties:

- Cooperating with community loan foundations to provide low-interest loans to low-income Vermonters for radon mitigation
- Designating a portion of new e-cigarette taxes collected to be used for the purpose of reducing radon risk
- Requiring that licensed radon professionals perform a certain number of hours per year of pro-bono mitigation work for low-income Vermonters could be a requirement for holding a license (ELI, 1993, pg. 22).
- Imposing a per-square-foot surcharge on new construction. This has been successfully implemented in Florida (ELI, 1993, pg. 22).
- Issuing bonds to raise funds for a radon program (ELI, 1993, pg. 22).
- Using fines and penalties collected from the violation of radon regulations to fund the radon program (ELI, 1993, pg. 22).

Private Homes

Radon Resistant New Construction

Overview

Radon Resistant New Construction (RRNC) is an emerging field of radon risk reduction designed to prevent radon entry into new homes and public buildings. The two dominant RRNC systems are active and passive sub-slab depressurization; more detailed information about them can be found in Appendix E.5. "Seven states [Illinois, Maryland, Michigan, Minnesota, New Jersey, Oregon, and Washington] in the U.S. require the installation of passive radon control systems as part of their residential building codes" (ELI, 2012, p. 35). The majority (5/7) of these states have either adopted or amended the radon control standard (an optional appendix) of the International Residential Code (IRC). Some of these states have designated RRNC mandates for only those areas within the EPA's Zone 1 of high-risk; the rest mandate statewide RRNC. Maine also includes RRNC in the statewide building code it established in 2008, but it leaves the decision to incorporate features of RRNC to the discretion of the homeowner or builder (ELI, 2012, p. 26).

The IRC calls for a passive system, "designed...to facilitate future 'active' radon mitigation" (ELI, 2012, p. 26); a passive system, when constructed correctly, can cause about a 50% reduction in radon levels; an active system, which requires increased energy usage, is much more effective (ELI, 2012). This is an important tradeoff to consider when weighing the benefits of each system.

The EPA estimates the cost to the builder as somewhere between $250 and $750, "depending on the size and location of the house", and the construction does not require uncommon skills or materials (EPA, 2001). This is significantly less than the cost of retrofitting a home, which usually runs from $1,500 to $2,500 (Chapter 2). In addition, implementing a radon control system into a new home may add to its value, according to the EPA (EPA, n.d.).

Policy Recommendations

Given the costs of mitigation, and ultimately, the costs associated with lung cancer treatment, it makes financial sense for new homes and buildings to come equipped with systems that minimize radon entry. However, instead of suggesting a politically infeasible amendment to Vermont's statewide building codes, we recommend directing local zoning boards to alter the

building codes of their specific jurisdictions. This directive could take the form of a mandate or an incentive for further research.

Certification

Overview

A radon mitigation certification program is used to ensure the integrity and skill level of professional radon testers and mitigators in the field. In addition, a certification program has the potential to create state revenue, institute a policy for pro bono mitigation work, and offset the costs associated with radon mitigation in public buildings by instituting specific requirements for inclusion.

Currently, Vermont has 12 radon mitigators who have received certification from third-party certification bodies, because Vermont has no state certification program. The Environmental Law Institute (ELI) suggests a “State Certification of Radon Professionals and Laboratories,” a prgram that covers testing, mitigating, and the necessary laboratory analyses. Currently 13 states have policies that establish a state certification program (see Appendix E.6). Within this larger umbrella, there is room for additional modifications: each have different mechanisms and requirements for enforcement, training, protocols, reporting, and other work practices.

- **Enforcement:** this would ensure accountability among the profession, through inspections/audits, license revocation, and checking for civil/criminal penalties. This requires the state to have adequate human and financial resources to enforce best practices.
- **Reporting**: this would require radon professionals to report the results of testing and mitigation activities to the state, to create a more broad statewide database.
- **Training and Examination**: this would require radon professionals to undergo state-specific radon testing and mitigation training as part of the certification process.
- **Other Work Practices**: includes quality assurance, worker health and safety, financial responsibility, and workers’ insurance. As of 2012, 12 of the 13 aforementioned states’ certification policies include quality assurance requirements.

California, Connecticut, and Virginia have not set up their own state certification program, but rather require third-party certification (ELI, 2012).

Policy Recommendations

As the cheapest and easiest option, Vermont should require AARST certification, and the VDH should maintain a publicly available directory of certified radon professionals. Inclusion within the directory would hinge upon performing a certain number of hours of pro bono mitigation per year—our recommendation is 15-20—and paying annual fees, which would go towards offsetting the costs of administering and creating the directory. This would be in addition to the requirements set forth by AARST.

Real Estate Transactions

Overview

Policies establishing mandatory disclosure or notification of radon testing status of a specific home are relatively common in the U.S., as is the provision of educational materials relating to radon testing. For Vermont, within the collection of real estate documents to be filled out during the point of sale, there is a specific form called the Seller's Property Inspection Report (Figure 4.4).

6. ADDITIONAL INFORMATION CONCERNING THE PROPERTY

(a)	Age of Building(s): Main Bldg. Additions to Main Bldg. Additional Building(s): (a) (b)			
(b)	Is Seller currently occupying the Property? If "No," how long has it been since Seller occupied?	YES	NO	
(c)	Has Seller built or caused to be built any of the buildings on the Property, or made any additions, modifications, alterations or renovations to any building on the Property? If "Yes," please explain:	YES	NO	
(d)	If "yes," did you obtain all necessary permits and approvals for such work?	YES	NO	
(e)	Are any property or development rights (e.g. conservation easements to Land Trusts, etc.) owned by others? If "Yes," by whom:	YES	NO	
(f)	Has Seller received written notice of any violations of local, state or federal laws, building codes and/or zoning ordinances affecting the Property?	YES	NO	
(g)	Are there any property tax abatements, land use tax stabilization agreements or other special property tax arrangements applicable to the Property?	YES	NO	DON'T KNOW
(h)	Has Seller received notice that the Property will be reassessed by any taxing authority during the next 12 months?	YES	NO	
(i)	Does the property have Urea-Formaldehyde Foam Insulation?	YES	NO	DON'T KNOW
(j)	Does the Property have Asbestos and/or Asbestos Materials in the siding-walls-plaster-flooring-insulation-heating system?	YES	NO	DON'T KNOW
(k)	Has the Property been tested for Radon Gas?	YES	NO	DON'T KNOW
(l)	If "Yes," when? By whom? Results:			
(m)	Does the Property have evidence of mold?	YES	NO	DON'T KNOW
(n)	If "Yes," what has been done about the mold?			
(o)	Are you aware of any off-site conditions in your neighborhood/community that could adversely affect the value or desirability of the Property, such as noise, proposed major new development, relocation or major construction of roads or highways, proposed zoning changes, etc.? If "Yes," explain in detail:	YES	NO	

Figure 4.4: Sellers Property Inspection Report. Lines (k) and (l) related to radon. Source: Katrina Spaulding, Vermont Realtors Association.

This form serves as a "CYA (cover your assets) for the realtors as a disclosure," but is not mandatory, and leaves the decision to test for radon up to the homebuyer (Spaulding, 2015). In addition, many realtors verbally convey information on radon to buyers and sellers—though this practice is also not mandated—and the practice varies between real estate offices (Katrina Spaulding, personal communication, March 18, 2015; Sarah Peluso, personal communication, April 6, 2015). As of 2012, 30 states have laws related to radon disclosure in "private, residential real estate transactions" (ELI, 2012). For a brief list and description of the options for disclosure laws, aggregated from the 1993 and 2014 ELI reports, see below.

Low Commitment:

- **"Encourage voluntary disclosure"** as part of legislative documents and consumer protection laws. This language would not show up in the real estate documents themselves.
- **Require general information** on radon hazards to be provided by the seller to the buyer before the "execution of a contract." This would not provide information about that specific home's radon levels; rather, it could be a separate document/warning statement, a fact sheet or pamphlet produced by the VDH or EPA, or a "signed buyer receipt." For example, New Hampshire's NH Rev. Stat. 477:4-a requires a warning statement and buyer receipt.

Medium Commitment:

- **Require specific disclosure** on a house's particular radon levels/disposition to radon hazards to be provided by the seller to the buyer before the "execution of a contract." Within this requirement, states could choose to do any of the following: mandate testing of homes pre-sale, then require sellers to disclose those test results; require sellers to provide radon-specific literature (like the EPA's *Home Buyer's and Seller's Guide to Radon),* then the opportunity for the buyer to test before contractually engaging in the sale of a home; require the disclosure of previous radon test results. The vast majority of states with disclosure laws in place have enacted this general type of law, but no state has yet mandated radon testing in real estate transactions.

High Commitment:

- **Mandate testing and mitigation** take place before the sale of the home; in this situation, the financial burden would fall on the seller, though it could be passed on to the buyer through sale price modification. There is currently no precedent set by other states' laws; however, New Jersey, Massachusetts, and Iowa each have enacted policies that mandate testing of other environmental health contaminants.
- **"Require general or specific disclosure by professionals"** would be a regulation in accordance with a state licensure program, in which real estate agents would have to be educated about radon hazards and provide that information to prospective sellers. This is a long shot, due to the stance of Vermont's powerful real estate lobby, who are wary of putting financial burden on brokers.

The 2012 ELI report suggests that the more content about radon is available to home buyers and sellers, "the more likely it will prompt action" (ELI, 2012, p.15). Katrina Spaulding, representing the lobbying arm of the Vermont Realtors Association, echoed this statement, but urged any future policy to be as unimposing as possible. She strongly discouraged mandates as a policy tool as a way of alleviating the financial burden on home buyers and sellers (Spaulding, 2015).

Policy Recommendations

Real estate agents should be educated about, and required to distribute, information relating to radon and other environmental health contaminants in homes. The EPA, via the VDH, already provides real estate agencies with literature relating to well-water contamination; the costs of providing an additional document with radon information would be negligible, and is categorized by the ELI as "low-commitment" (see above). While it would be optimal to make the Sellers Property Inspection Report mandatory, it would likely encounter pushback from the real estate lobby, and it is generally already common practice to complete it.

Mandatory Testing and Mitigation

Schools

Overview

Children and employees spend a large portion of their lives in schools, making them an important policy target. Studies suggest that children may be especially at risk to radon exposure; by the age of 10, children on average have received twice the dose of radon in their lungs than adults over a period of 10 years, due to more time spent inside and the shape of children's lungs. (UM School of Public Health Class 5104, n.d.). Children's increased vulnerability to secondhand tobacco smoke also suggests that they may be more vulnerable to radon gas (EPA, 2010). However, more research is needed on this topic. Given currently available information on radon levels in Vermont's schools and the dose-response curve presented in Chapter 2, we anticipate that reducing the radon concentration to 2 pCi/L in all schools currently above the action level would prevent the deaths of 33 Vermont schoolchildren, though this is likely an underestimate (see Appendix E.7).

Several policy options exist for reducing radon levels in Vermont's schools. First, the legislature could encourage schools to test without explicitly requiring them to do so, as was done in Illinois and Minnesota (ELI, 2014a). Second, the legislature could require radon testing in schools, an approach taken by the state of Florida (ELI, 2014a). Third, the legislature could require schools to test *and* to publicly disclose their test results, as mandated by Colorado, Connecticut, and Virginia (ELI, 2014a). Currently, no state requires both testing and mitigation when high levels are detected.

Though the state government has not yet taken any action on this matter, several non-profits have organized efforts to reduce the radon risk in Vermont's schools. The American Lung Association of the Northeast, based in Williston, has made increased testing in Vermont schools a lobbying priority. Furthermore, the Association of Vermont Radon Industry Professionals (AVRIP) led by mitigation contractor Peter Crowley has provided no-cost mitigation services to several Vermont schools by donating their labor and seeking donated materials from hardware suppliers.

Policy Recommendations

We recommend requiring testing in all public Vermont school buildings *and* disclosure of the results. Testing without disclosure is insufficient for two reasons: it fails to inform the public of their health risk and does not encourage mitigation. Several Vermont schools who have voluntarily tested for radon and found elevated concentrations have hidden this information from the community largely to avoid dealing with a costly mitigation (P. Crowley, personal communication, March 30, 2015). Requiring mitigation in schools that test high would add a huge burden to school districts when considering that radon school mitigation costs can range from $5,000 - $75,000 depending on the extent of the problem and the complexity of the school's HVAC system (Crowley). Therefore, we feel that mitigation should be a municipal-level decision. Requiring schools to test and disclose for radon will permit parents and faculty to make informed decisions about radon management without placing a significant financial burden on schools.

In this era of tight budgets, one of the major themes in Vermont education policy is reducing the burdens (or at least not adding additional burdens) to beleaguered Vermont public

schools. As a result, the legislature will need to find creative ways to provide support for testing and mitigation.

One way to reduce the cost of radon testing is to incorporate testing into the science curriculum. VDH's test kits are low cost ($10/kit) and easy to use—one must simply remove them from the packaging and place them in an appropriate location. With appropriate guidance for placement of the kits, a science class could easily perform this task while simultaneously learning about environmental health, radioactivity, or geology. Schools could also incorporate radon testing into existing community service programs as detailed in Chapter 3.

The state could look for ways to provide schools with free mitigation labor to avoid having to raise more funds. If the state required 16 hours of pro bono work from each mitigator, 320-400 hours of no-cost mitigation work would be available every year for schools, as AVRIP director Peter Crowley anticipates that 20-25 radon professionals would acquire a license under a statewide certification program.

We further recommend that the legislature reinstate programs which in the past provided schools with the resources to address a wide variety of environmental health problems. For example, the Envision program, authorized under Act 125, originally provided yearly grants of up to $5,000 to help schools with implementing environmental health efforts. Sadly, this aspect of the Envision program has been eliminated. Similarly, the School Facilities & Construction program of the Agency of Education formerly administered cost-share programs for schools that demonstrated an urgent need for construction, covering up to 75% of the construction costs with state aid. This program, too, has been suspended by the legislature (Vermont Agency of Education, 2013). In lieu of reinstating this program as it previously existed, the legislature could also consider creating a revolving fund to assist schools with radon management through a combination of grants and low- or no-interest loans, a strategy which has proven effective in Maine (Maine Department of Education, 2015).

Finding ways to provide schools with the materials necessary for testing and mitigation might be more complicated. As mentioned previously, Peter Crowley of AVRIP performs approximately one no-cost school mitigation per year by donating labor and seeking donated materials (Crowley, 2015). Schools could reach out to other nonprofits such as the American Lung Association or Informed Green Solutions for funding or assistance in applying for grants.

Prisons

Overview

Prisons house the greatest concentration of individuals at risk to radon of any class of public building. Depending on the length of their sentence, the majority of prisoners spend considerably more time inside than even children do in schools. Additionally, up to 80% of prisoners nationwide are smokers or former smokers, which elevates their risk of radon-induced lung cancer (Cork, 2012, pg. 3). Since the State of Vermont pays for inmates' medical care, it is in the state's interest to prevent costly cases of lung cancer. While prisons may lack the cultural salience that schools have, Vermont has an excellent opportunity to be the first state to address this important issue of environmental justice.

Policy Recommendations

We recommend that the State of Vermont require radon testing in Vermont's seven prisons, none of which have ever been tested for radon according to David Burley, Regional Director for Buildings at Vermont's Department of Corrections. Following the EPA's testing protocols for large buildings, this would cost $10,850 (however, see Appendix E.8 for a discussion of testing protocols in prisons). Once there is more data about radon levels in Vermont's prisons, the legislature, Department of Health, and the Department of Corrections can collaborate to come up with an effective radon management plan.

Rentals & Subsidized Housing

Overview

Requiring radon testing and disclosure in rental properties provides a unique opportunity to mitigate the health risks associated with radon exposure among lower income, underrepresented Vermonters who legally have less control over their housing environment than homeowners. 29% of Vermonters are renters, meaning that legislation affecting rental properties would affect over 93,000 housing units (Department of Numbers, 2013; United States Census Bureau, 2013).

Several states require Radon-Resistant New Construction methods in new affordable housing developments; however, no state has laws specifically pertaining to testing or mitigation in existing affordable housing structures (ELI, 2014b). Policies regarding rental housing may be extended to subsidized housing. Additionally, ELI recommends providing financial assistance in

the form of grants or low-interest loans to landlords of low-income housing complexes to ensure that landlords do not raise the rents to offset the cost of radon testing and mitigation (ELI, 2012, p. 33).

There are currently no specific stipulations surrounding radon in rental housing units according to the Vermont Department of Health Rental Housing Health Code (2006). At the federal level, there may be some programs used to help fund radon reduction in homes that are affordable to limited income families. Funding is typically allocated to local agencies or groups, which then fund the mitigation. The EPA acknowledges that "rental property owners are *usually* responsible for keeping their properties in a safe and fit condition" and recommends that "if your radon testing shows high radon levels, you should inform the building owner in writing" (EPA, "A Radon Guide for Tenants," 2010). A report from the Environmental Law Institute addresses the limited legal applicability of general habitability standards to issues of radon exposure in rental units: "While general habitability and good repair provisions found in housing codes and landlord-tenant laws are potentially relevant to situations where tenants are exposed to elevated radon levels, they may not provide a strong foundation for effective public enforcement or private (tenant) legal action to reduce elevated radon levels" (ELI, "Indoor Air Quality in Rental Dwellings," 2014). According to the EPA, existing laws that require landlords to keep their properties in a safe and fit condition may apply to radon levels. However, the Environmental Law Institute recently published a report claiming that existing landlord-tenant laws do not provide a "strong foundation for … legal action to reduce elevated radon levels (ELI, 2014)

While some policies addressing radon in rental units have been implemented in other states, the efficacy of these policies is largely unknown as data on compliance are limited. A summary of the most progressive policies can be found in Appendix E.9. (ELI, "Radon Laws Database," 2014). The most advanced policy is that of Maine, which requires testing and disclosure of results in all rental properties.

Policy Recommendations

We recommend requiring testing and disclosure of test results to current and prospective tenants in all rental properties. We feel that requiring landlords to test their properties would have a positive impact on the health of a lower-income population without placing an unreasonable financial burden on landlords, given the low cost of test kits. The main opposition

to this policy may come from landlords attempting to avoid responsibility for or knowledge of a potential public health issue on their properties.

One option for renters is to leverage Vermont's culture of local government participation to encourage tenants to communicate with one another, test their units using a free VDH test kit, and thus pressure their landlord to act if high radon levels are found. Legal action to force testing or mitigation is currently not a feasible option for renters, but small-scale coalitions may provide the necessary pressure to reduce dangerous levels of radon in rental units. Promoting collaboration among tenants could be a promising route for future education and outreach efforts.

Businesses

Overview

Private business establishments are an important type of property to consider for radon testing and mitigation, as employees spend many hours of their lives in their workplaces. Regulations of radon levels in state and local government buildings would affect over 4 million square feet of office space and over 35,000 employees (Vermont Department of Buildings and General Services, 2015; United States Census Bureau, 2014). Extending these regulations to all places of business would affect up to 260,000 employed individuals throughout the state (Vermont Department of Labor, 2015).

OSHA radon exposure standards in the workplace are much higher than the EPA's recommended action level of 4.0 pCi/L and are based on regulations originally crafted in the 1970s by the Nuclear Regulatory Commission (Pennsylvania DEP, 2008). According to professional radon mitigator Peter Crowley, standards for the general workforce tend to be much higher than those for radon mitigation professionals (Crowley, 2015). Vermont has a "Complete State Plan" which governs its workplace exposure standards and is independent of OSHA regulation, but its regulations for radon exposure in private places of business are the same as federal OSHA regulations, meaning that they are based on the same outdated standards of the Nuclear Regulatory Commission (Vermont Department of Labor 2014). The standard for radon can be found in 10 CFR Part 20, Appendix B, Table 1 of the Nuclear Regulatory Commission's regulations for "Ionizing Radiation" (NRC, "NRC Regulation Title 10"), and is 100 pCi/L. The EPA has no guidance that applies specifically to places of work (Pennsylvania DEP 2008).

Other state policies regarding exposure to radon in the workplace generally delegate setting standards or investigating indoor air quality (IAQ) complaints to state offices of health or human services, which may face issues with enforcement. These can be found in Appendix E.10 (ELI, “Radon Laws Database,” 2014).

Policy Recommendations

We recommend that Vermont require private business owners to test their properties and disclose the results to employees. We currently do not recommend requiring testing in state and local government buildings, as this would put increased strain on VDH resources, although RRNC building codes should be implemented in all future government building projects. Although there is little precedent for establishing a workplace radon exposure standard in other states, Vermont should set its own workplace standards for radon exposure that match EPA’s action level (4 pCi/L) or WHO’s action level (2.7 pCi/L) in Vermont’s “Complete State Plan”. To ease the financial burden of testing on private business owners, we recommend that VDH sell test kits to businesses at cost ($10/kit).

Placing requirements for radon testing on private businesses in Vermont may also have the added benefit of encouraging mitigation through market forces. With all business owners required to communicate the risk that radon poses to their employees, workers would favor businesses with low radon levels. This would encourage businesses with especially high radon levels to mitigate their radon issue in hopes of providing an attractive workplace for prospective employees.

Conclusion

Radon is not on the forefront of most Vermonters’ minds, and it likely never will be. Similarly, we realize that the legislature always has a lot on their plate, and it may seem like there is no time to address radon. Should Vermont ignore its radon problem, however, it will cost hundreds of Vermonters their lives in the next several years. We have compiled a set of options that, in the policy world, are fairly inexpensive and not very complex. Any of these options, however, would have a major health impact, even if it is not immediately noticeable. We hope the legislature will seriously consider at least some of the options that we have presented, at least so that Vermont catches up with its neighbors. However, if the legislature were to seriously

consider all of the options that we have presented, Vermont would have a chance to move beyond catching up by leading the charge for more comprehensive radon legislation nationwide. Given Vermont's progressive political history, we hope that the Vermont legislature is prepared to lead a charge against a major public health issue that will save tens of thousands of lives in the coming years.

Bibliography

Akerblom, G., & Lindgren, J. (1997). Mapping of groundwater radon potential.

Appleton, J.D. (2009). Radon: Sources, Health Risks, and Hazard Mapping. *Royal Swedish Academy of Sciences*, *36*(1), 85-89. Retrieved January 27, 2015, from http://www.jstor.org/stable/4315791

Billig, S. (2000). Research on K-12 school-based service-learning: The evidence builds. *Phi Delta Kappan*, 658.

Children's Environmental Health Network (2008, June). *Radon*. Retrieved from http://www.cehn.org/drupal/files/education/radon_factsheet.pdf.

Choubey, V. M., & Ramola, R. C. (1997). Correlation between geology and radon levels in groundwater, soil and indoor air in Bhilangana Valley, Garhwal Himalaya, India. *Environmental Geology*, *32(4)*, 258-262.

Cipriano, L. E., Romanus, D., Earle, C. C., Neville, B. A., Halpern, E. F., Gazelle, G. S., & McMahon, P. M. (2011). Lung cancer treatment costs, including patient responsibility, by stage of disease and treatment modality, 1992–2003. *Value in health : the journal of the International Society for Pharmacoeconomics and Outcomes Research*, 14(1), 41-52.

Cohen, B. L. (1986). A national survey of 222Rn in U.S. homes and correlating factors. *Health Physics, 51(2),* 175-183.

Cohen, B. L. (1991). Variation of radon levels in U.S. homes correlated with house characteristics, location, and socioeconomic factors. *Health Physics, 60(5),* 631-642.

Cohen, B. L., & Gromicko, N. (1988). Variation of radon levels in U.S. homes with various factors. *JAPCA*, *38(2),* 129-134.

Cork, K. (2012). *Tobacco Behind Bars: Policy Options for the Adult Correctional Population*. Public Health Law Center. Retrieved from http://publichealthlawcenter.org/sites/default/files/resources/phlc-policybrief-tobaccobehindbars-adultcorrections-2012.pdf.

Cothern, C. R. (1990). *Radon, radium, and uranium in drinking water*. CRC Press.

Crowley, P. (2014). [Radon mitigation project data]. Unpublished raw data.

Damerell, P., Howe, C., & Milner-Gulland, E. J. (2013). Child-orientated environmental education influences adult knowledge and household behaviour. *Environmental Research Letters*, *8*(1), 015016.

Department of Numbers. (2013). *Vermont Residential Rent and Rent Statistics*. Retrieved April 17, 2015 from http://www.deptofnumbers.com/rent/vermont/.

Dockins C., Maguire M., Simon N., & Sullivan M. (2004). Value of Statistical Life Analysis and Environmental Policy: A White Paper U.S. Environmental Protection Agency National Center for Environmental Economics April 21, 2004. Retrieved from http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0483-01.pdf/$file/EE-0483-01.pdf

Duvall, J., & Zint, M. (2007). A review of research on the effectiveness of environmental education in promoting intergenerational learning. *The Journal of Environmental Education*, *38*(4), 14-24.

Environmental Law Institute. (1993). *State Radon Legislation - Issues and Options*. Retrieved April 17, 2015 from http://www.eli.org/sites/default/files/eli-pubs/d1_13.pdf.

Environmental Law Institute. (2014). Database Excerpt: Radon Laws. *Database of State Indoor Air Quality Laws*. Retrieved April 16, 2015 from http://www.eli.org/sites/default/files/eli-pubs/2014-radon-database.pdf.

Environmental Law Institute. (2014). *Indoor Air Quality in Rental Dwellings.* Retrieved from http://www.eli.org/buildings/indoor-air-quality-rental-dwellings.

Environmental Protection Agency. (n.d.) *Builders: Basic Techniques.* Retrieved May 9, 2015, from http://www.epa.gov/radon/rrnc/basic_techniques_builder.html.

Environmental Protection Agency (EPA). (1993). *Radon Measurement in Schools: Revised Edition*. Retrieved May 5, 2015, from http://www.epa.gov/radon/pdfs/radon_measurement_in_schools.pdf.

Environmental Protection Agency (EPA). (2003). Radon Health Risks. *EPA: Radon (Rn)* Retrieved March 4, 2015, from http://www.epa.gov/radon/healthrisks.html

Environmental Protection Agency. (2010). *A Physician's Guide to Radon.* Retrieved April 16, 2015 from http://www.epa.gov/radon/pubs/physic.html.

Environmental Protection Agency (EPA). (2010). *A Radon Guide for Tenants.* Retrieved http://www.epa.gov/radon/pubs/tenants.html.

Environmental Protection Agency (EPA). (2013). A Citizen's Guide to Radon. Retrieved May, 2015 from http://www.epa.gov/radon/pubs/citguide.html.

Field, B. (2012, March 28). The Radon Threat Is Still With Us. *The New York Times.* The Opinion Pages. Web.

Floyd, J. E. (n.d.). *Topic 2: Interest rates and asset values.* Retrieved from http://www.economics.utoronto.ca/jfloyd/modules/irav.html

Ford, E., Kelly, A., Teutsh, S., Thacker, S., & Garbe, P. (1999). Radon and Lung Cancer: A Cost-Effectiveness Analysis. *American Journal of Public Health,* 89(3), 351-357.

Gilbert, D., QTD in Marshall, G.(2014, August 18). Understand faulty thinking to tackle climate change. New Scientist. Retrieved April, 2015, from http://www.newscientist.com/article/mg22329820.200PunderstandPfaultyP thinkingPtoPtacklePclimatePchange.html#.VMpOAHYb6EQ

Green Mountain Power (2015). Customer statement.

Guiseppe, Vincente E. (2006) *Radon in groundwater: A study of the measurement and release of waterborne Radon and modeling of Radon variation in bedrock wells (Thesis)*. University of Maine.

Front Matter. (1999). Health Effects of Exposure to Radon: BEIR VI . Washington, DC: The National Academies Press,

Henschel, D. B. (1994). Analysis of radon mitigation techniques used in existing U.S. houses. *Radiation Protection Dosimetry*, *56*(1-4), 21-27.

Hill, P. L., Kucks, R. P., & Ravat, D. (2009). *Aeromagnetic and Aeroradiometric Data for the Conterminous United States and Alaska from the National Uranium Resource Evaluation(NURE) Program of the U. S. Department of Energy*.

Hill, W.G., Butterfield, P., & Larsson, L.S. "Rural Parents' Perceptions of Risks Associated with Their Children's Exposure to Radon." *Public Health Nursing* 23.5 (2006): 392-99. Web.

Hopke, P. K., Borak, T. B., Doull, J., Cleaver, J. E., Eckerman, K. F., Gundersen, L. C. S., ... & Simon, S. L. (2000). Health risks due to radon in drinking water. *Environmental science & technology*, *34*(6), 921-926.

Johnson Jr, R. H., Bernhardt, D. E., Nelson, N. S., & Calley Jr, H. W. (1973). *Assessment of potential radiological health effects from radon in natural gas*. Environmental Protection Agency, Washington, DC (USA). Office of Radiation Programs.

Karpinska, M., Mnich, Z., Kapala, J., & Szpak, A. (2009). The evaluation of indoor radon exposure in houses. *Polish Journal of Environmental Studies, 18(6),* 1005-1012.

Lantz, P., Mendez, D., & Philbert, M. (2013). Radon, Smoking and Lung Cancer: The Need to Refocus Radon Control Policy. *American Journal of Public Health*, 103(3), 443-447.

Latour, Michael S., and John F. Tanner. "Radon: Appealing to Our Fears." *Psychology and Marketing* 20.5 (2003): 377-94. Web.

Létourneau, E.G., D. Krewski, J.M. Zielinski and R.G. McGregor. 1992. Cost Effectiveness of Radon Mitigation in Canada. Radiation Protection Dosimetry 45 (1-4): 593-598.

Lewis, R.K. (2008). *Radon in the Workplace: The OSHA Ionizing Radiation Regulations*. Retrieved from https://www.aarst.org/proceedings/2004/2004_07_Radon_in_the_Workplace_The_OSHA_Ionizing_Radiation.pdf.

Linville, P.W., Fischer, G.W. (1991). Preferences for separating and combining events: a social application of prospect theory and the mental accounting model. *Journal of Personality and Social Psychology*, 60, 5–23.

Maine Department of Education. (2015). School Revolving Renovation Fund. Retrieved May 9, 2015 from http://www.maine.gov/doe/facilities/renovation/index.html.

Mandel, P. (2013). Children as Change Agents: The Influence of Integrating Environmental Education into Home Learning Projects on Families and Community Members. 75-79.

Melton, P. (2014). Radon and Schools: A Study in Denial. *Environmental Building News*, *23*(1). Retrieved May 9, 2015 from https://www2.buildinggreen.com/article/radon-and-schools-study-denial?ip_login_no_cache=198da39bdc229e0ba36abf666db8bca3.

Morabito, S. (2014, January 1). Tobacco Prevention, Cessation and Control Program budget recommendations from VT Tobacco, Evaluation & Review Board [18 V.S.A. Sec. 9505 (9)] [Agency of Human Services]. Retrieved January 1, 2015, from http://www.leg.state.vt.us/reports/2014ExternalReports/302184.pdf

Muessig, K. W. (1988). Correlation of airborne radiometric data and geologic sources with elevated indoor radon in New Jersey. In *The 1988 Symposium on Radon and Radon Reduction Technology, preprints. Research Triangle Park, North Carolina: U.S. Environmental Protection Agency, Air and Energy Environmental Research Laboratory*.

National Research Council (1999). Health Effects of Exposure to radon: BEIR VI. *Committee on Health Risks of Exposure to Radon*.

NRDC "The Story of Silent Spring." 12 May 2013. Web. http://www.nrdc.org/health/pesticides/hcarson.asp

Nuclear Regulatory Commission. (n.d.). *NRC Regulation Title 10, Code of Federal Regulations. Part 20—Standards for Protection Against*

Radiation. Radionuclides. Retrieved http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Radon-222.html.

O’Brien, K.E., Risk, D., Rainham, D., O’Beirne-Ryan, A.M. (2014). Using field analogue soil column experiments to quantify radon-222 gas migration and transport through soils and bedrock of Halifax, Nova Scotia, Canada. Journal of Environment and Earth Science, 72(7), 2607-2620.

Office of Air Quality Planning and Standards Office of Atmospheric Programs U.S. Environmental Protection Agency. *Chapter 4: Cost-Benefit Comparison.* (1999). In *REGULATORY IMPACT ANALYSIS FOR THE FINAL SECTION 126 PETITION RULE* (pp. 80-98). Washington D.C.

Otton, J. K. (1992). *The geology of radon*. U.S. Department of the Interior, U.S. Geological Survey.

Pennsylvania Department of Environmental Protection. (2015). *Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) Study Report*.

Petersen, M., & Larsen, T. (2006). Cost–benefit Analyses of Radon Mitigation Projects. Journal of Environmental Management, 81(1), 19-26.

RadonAway. (2012). *Fan operating cost calculator.* Retrieved from http://www.radonaway.com/radon-fan-operating-cost-calculator.php

Rao, H., Greve H. R., and G. F. Davis. Fool's Gold: Social Proof in the Initiation and Abandonment of Coverage by Wall Street Analysts. *Administrative Science Quarterly* 46.3 (2001): 502-26. *Sage Journals*. Web.

Rinker, G., Hahn, E., & Rayens, M. (2014). Residential Radon Testing Intentions, Perceived Radon Severity and Tobacco Use. *Journal of Environmental Health*, 76(6), 42-47.

Rugg, M. (1988). House age, substructure and heating system: Relationships to indoor radon concentrations.*pp. III-P*.

Sandman, P. M., & Weinstein, N.D. "Predictors of Home Radon Testing and Implications for Testing Promotion Programs." *Health Education & Behavior* 20.4 (1993): 471-87. *Sage Journal*. Web.

Sethi, T., El-Ghamry, M., & Kloecker, G. (2012). Radon and Lung Cancer. *Clinical Advances in Hematology & Oncology, 10*(3), 157-164. Retrieved from http://www.hematologyandoncology.net/files/2013/05/ho0312_sethi1.pdf

Scheib, C., Appleton, D., Jones, D., & Hodgkinson, E. (2006). Airborne uranium data in support of radon potential mapping in Derbyshire, Central England.

Schumann, R. R., & Gundersen, L. C. (1996). Geologic and climatic controls on the radon emanation coefficient. *Environment International*, *22*, 439-446.

Sethi, T., El-Ghamry, M., & Kloecker, G. (2012). Radon and Lung Cancer. *Clinical Advances in Hemotology & Oncology*, 10(3).

Sheeran, P., Harris, P.R., & Epton, T. "Does Heightening Risk Appraisals Change People's Intentions and Behavior? A Meta-Analysis of Experimental Studies." *Psychological Bulletin* (2013): n. pag. Web.

Shendell, D. G., & Carr, M. (2013). Physical conditions of a house and their effects on measured radon levels: data from Hillsborough Township, New Jersey, 2010-2011. *Journal of environmental health*, *76*(3), 18-24.

Shweikani, R., Giaddui, T. G., & Durrani, S. A. (1995). The effect of soil parameters on the radon concentration values in the environment. *Radiation measurements*, *25*(1), 581-584.

Skeppström, K., & Olofsson, B. (2006). A prediction method for radon in groundwater using GIS and multivariate statistics. *Science of the total environment*, *367*(2), 666-680.

Stavins, R. (2000). An SAB Report on EPA's White Paper Valuing the Benefits of Fatal Cancer Risk Reduction.

University of Minnesota School of Public Health Class 5104. (n.d.) *Radon for Kids*. Retrieved from http://enhs.umn.edu/hazards/hazardssite/radon/radonforkids.html.

United States Census Bureau, Census 2000 Summary File 3. www.infoplease.com/us/census/data/vermont/housing.html Accessed: May 10, 2015.

United States Census Bureau. (2010). *Profile of General Population and Housing Characteristics: 2010*.

United States Census Bureau: State and County Quick Facts. (2013). *Data derived from Population Estimates, American Community Survey, Census of Population and Housing, State and County Housing Unit Estimates, County Business Patterns, Non-employer Statistics, Economic Census, Survey of Business Owners, Building Permits, Consolidated Federal Funds Report*.

United States Census Bureau. (2014, Dec. 19). *State and Local Government Employment and Payroll Data*. Retrieved from http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

United States Census Bureau (2015, Mar. 31). *Vermont Quickfacts*. Retrieved from http://quickfacts.census.gov/qfd/states/50000.html.

United States Department of Labor. (2015). *Consumer Price Index*. Retrieved from Bureau of Labor Statistics: http://www.bls.gov/cpi/.

United States Environmental Protection Agency. (2003a). Consumer's Guide to Radon Reduction. 402-K-03-002, Revised February 2003. Retrieved from http://www.epa.gov/radon/images/consguid.pdfS.

United States Environmental Protection Agency. (2003b). *EPA assessment of risks from radon in homes* (EPA 402-R-03-003). Washington, DC: U.S. Government Printing Office.

United States. Environmental Protection Agency. Risk Assessment Forum. (2005). Guidelines for carcinogen risk assessment. Risk Assessment Forum, U.S. Environmental Protection Agency.

United States Environmental Protection Agency. (2006). *Report of the EPA Workgroup on VSL Meta-Analysis*, Washington, DC: U.S. Government Printing Office.

United States Environmental Protection Agency. (2010). *The Emissions & Generation Resource Integrated Database (eGRID).* Revised August 2014. http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

United States Geological Survey. (1993). *Geologic Radon Potential of EPA Region 1*.

United States White House (2001). *Ranking Regulatory Investments in Public Health.* https://www.whitehouse.gov/sites/default/files/omb/inforeg/spec24.pdf.

Vermont Agency of Education. (2015). School Facilities & Construction. Retrieved May 9, 2015 from http://education.vermont.gov/school-facilities-and-construction.

Vermont Department of Buildings and General Services. (2015). Retrieved from http://bgs.vermont.gov/.

Vermont Department of Education. (2014). *School Enrollment Report*.

Vermont Department of Health. (2010). *Lung Cancer in Vermont*. Retrieved from http://healthvermont.gov/prevent/cancer/documents/lung_cancer_in_vermont.pdf

Vermont Department of Health (2015). *Radon.* Retrieved from http://healthvermont.gov/enviro/rad/Radon.aspx

Vermont Department of Health. (2006). *Rental Housing Health Codes*. Retrieved from http://www.healthvermont.gov/regs/Rental_Housing_Code.pdf.

Vermont Department of Labor. (2014). *Compliance Assistance*. Retrieved from http://labor.vermont.gov/vosha/compliance-assistance/.

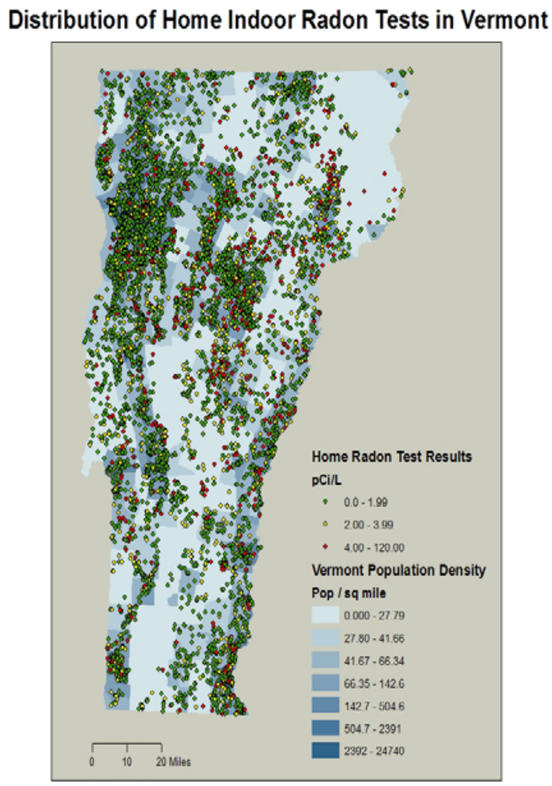
Vermont Public Interest Research Group. (1994). VPIRG Radon/IAQ Work Plan. University of Vermont, Special Collections. Retrieved March 9, 2015.

Vinson, D. S., Vengosh, A., Hirschfeld, D., & Dwyer, G. S. (2009). Relationships between radium and radon occurrence and hydrochemistry in fresh groundwater from fractured crystalline rocks, North Carolina (USA). *Chemical Geology*, *260*(3), 159-171.

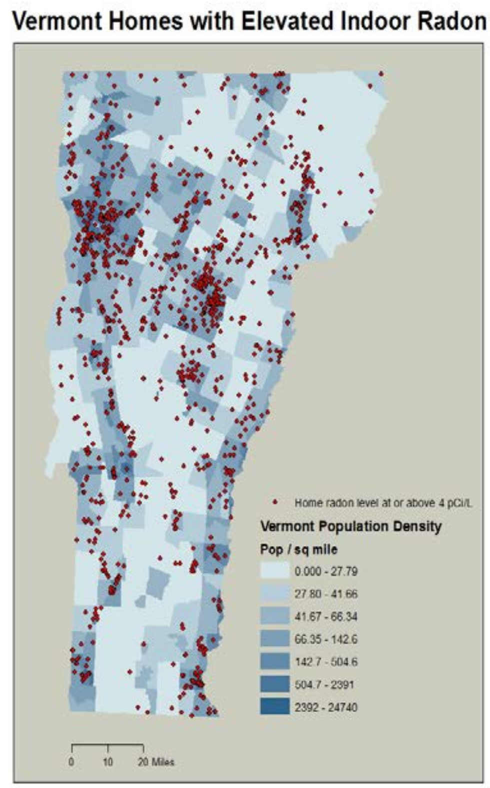
Viscusi, W. K., & Aldy, J. E. (2003). The value of a statistical life: a critical review of market estimates throughout the world. *Journal of risk and uncertainty*, *27*(1), 5-76.

Wanty, R. B., Johnson, S. L., & Briggs, P. H. (1991). Radon-222 and its parent radionuclides in groundwater from two study areas in New Jersey and Maryland, USA. *Applied Geochemistry*, *6*(3), 305-318.

Appendix A: Geospatial Metadata



Map A.



Map B.

Title: Distribution of Indoor Home Radon Tests in Vermont
Authors: Fernando Sandoval, Mary Richards, Dylan Sinnickson, Kevin Wood,
Date: April 21st, 2015
Scale: Vermont (1: 1,250,000)

GIS Files:

- RadonAirTest9413_GeocodedMatched_Sept2013_ResultsOnlyShareVersion
    - Vermont Geological Survey
- VT_proj_join.shp (Vermont population data per census block)
    - Middlebury Department of Geography

Steps: Project RadonAirTest9413 to VT_proj_join.shp, Select by attribute, Export as new Layer

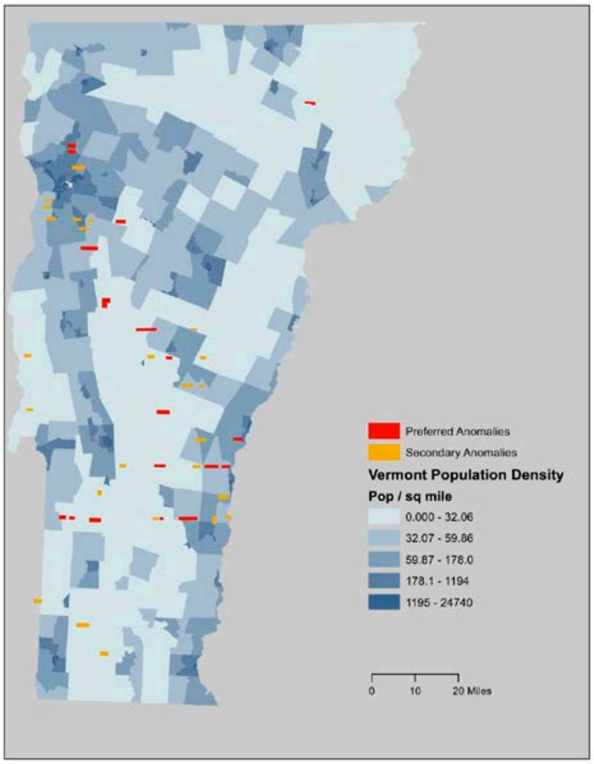
Results:

Test < 2: 8335/11714: 71.2%
2 = test<4: 1961/11714: 16.7%
Test >=4: 1418/11714: 12.1%

- 87.9% are below EPA action level
- Distribution appears to generally match pop density
- Distribution of Indoor Home Radon Tests in Vermont

Map A shows home radon tests as points on a map of Vermont census tracts shaded by population density. There appears to be a trend of more tests occurring in population-dense areas. The tests were divided into three categories by their results: 0-2 pCi/L, 2-4 pCi/L, and 4+ pCi/L. These divisions are representative of radon mitigation; the EPA recommends action be taken at 4+ pCi/L and most radon mitigation projects can effectively reduce radon levels to 2 pCi/L. Within Vermont, 71.2% of tests are 0-2 pCi/L, 16.7% are 2-4 pCi/L, which means that 87.9% are below the EPA action level, and 12.1% are 4 pCi/L or greater. Map B is similarly constructed but only displays the tests that recorded levels above 4 pC/L, which reveals the distribution of homes that need radon mitigation.

Vermont NURE Anomalies



Metadata for Anomalies map
Title: Distribution of Indoor Radon Tests within Preferred and Secondary Aerial Anomalies
Authors: Dylan Sinnickson, Innocent Tswamuno
Date: April 7, 2015
Scale: Vermont (1:1,250,000)

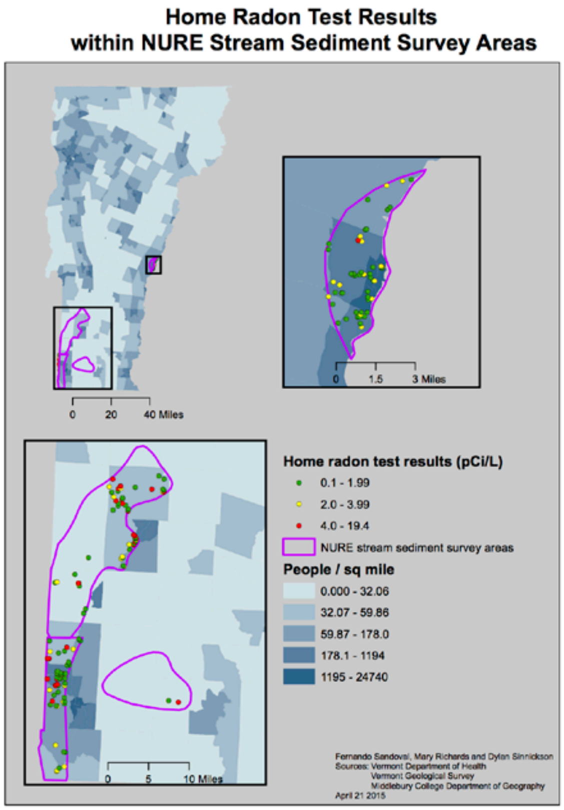
GIS files:
Preferred Anomalies (digitized polygons based on data from the NURE airborne radioactivity survey)
-Source Vermont Geological Survey (VGS)

Secondary_Anomalies (digitized polygons based on data from the NURE airborne radioactivity survey)
- Source Vermont Geological Survey (VGS)

VT_proj_join (Vermont population data per census block)
- Source Middlebury Department of Geography

RadonAirTest9413_GeocodedMatched_Sept2013_ResultsOnlyShareVersion (Measurements of home radon tests throughout Vermont)
- Source Vermont Department of Health (VDH), Vermont Geological Service (VGS)

Operations: Project, Intersect, Union, Symmetrical Difference, Select by Attribute (<2, >=2 ; <4, and >4)



Title: Home Radon Test Results within NURE Stream Sediment Areas
Authors: Fernando Sandoval, Mary Richards and Dylan Sinnickson
Date: April 21, 2015
Scale: Vermont (1:1,250,000)

Description:

This map shows the distribution of home radon tests within areas identified as having high levels of uranium by NURE stream sediment surveys. Home radon tests are shown as points and are color-coded to reflect the severity of the radon contamination. The divisions, 0-2 pCi/L, <2 - <4, pCi/L, and >= 4 pCi/L, reflect radon mitigation standards. 4 pCi/L is considered the safe level by the EPA, and 2 pCi/L is generally considered the level to which radon mitigation is effective. The purple polygons identify areas in which high levels of uranium were found by NURE steam sediment tests.

Of all of the indoor home radon tests, only 1.5% (177 of 11537) fell within the high uranium stream sediment polygons. Within this subset, however, the frequency of higher indoor radon readings is greater than in the rest of Vermont: 9 percent fewer homes have an indoor radon reading of <2 picocuries per liter, 5.9 percent more homes have a reading between 2 and 4 picocuries per liter, and 3.8 percent more homes have a reading of 4 or more picocuries per liter (see table below).

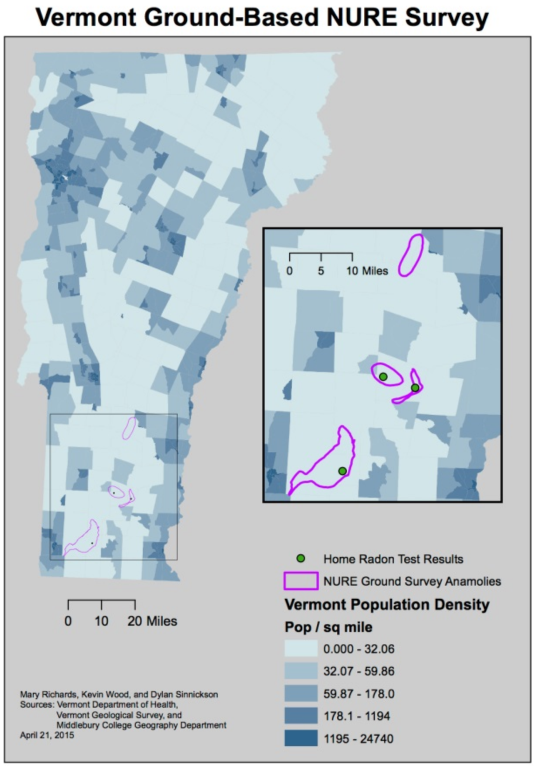
	Inside	**% inside**	**outside**	**% outside**	**% difference (%in - % out)**
<2	109	61.581921	8226	71.301031	-9.71911056
>=2 and <4	40	22.59887	1921	16.650776	5.948094292
>=4	28	15.819209	1390	12.048193	3.771016268

GIS files:

- RadonAirTest9413_GeocodedMatched_Sept2013_ResultsOnlyShareVersion
    - Source: Vermont Department of Health (VDH)
- vt _nure_stream.shp
    - Source: Vermont Geological Survey (VGS)

Lineage

1. Obtained tests results within vt _nure_stream.shp polygons using INTERSECT (Analysis)
2. Obtained tests results outside VT NURE stream polygons using ERASE (Analysis)



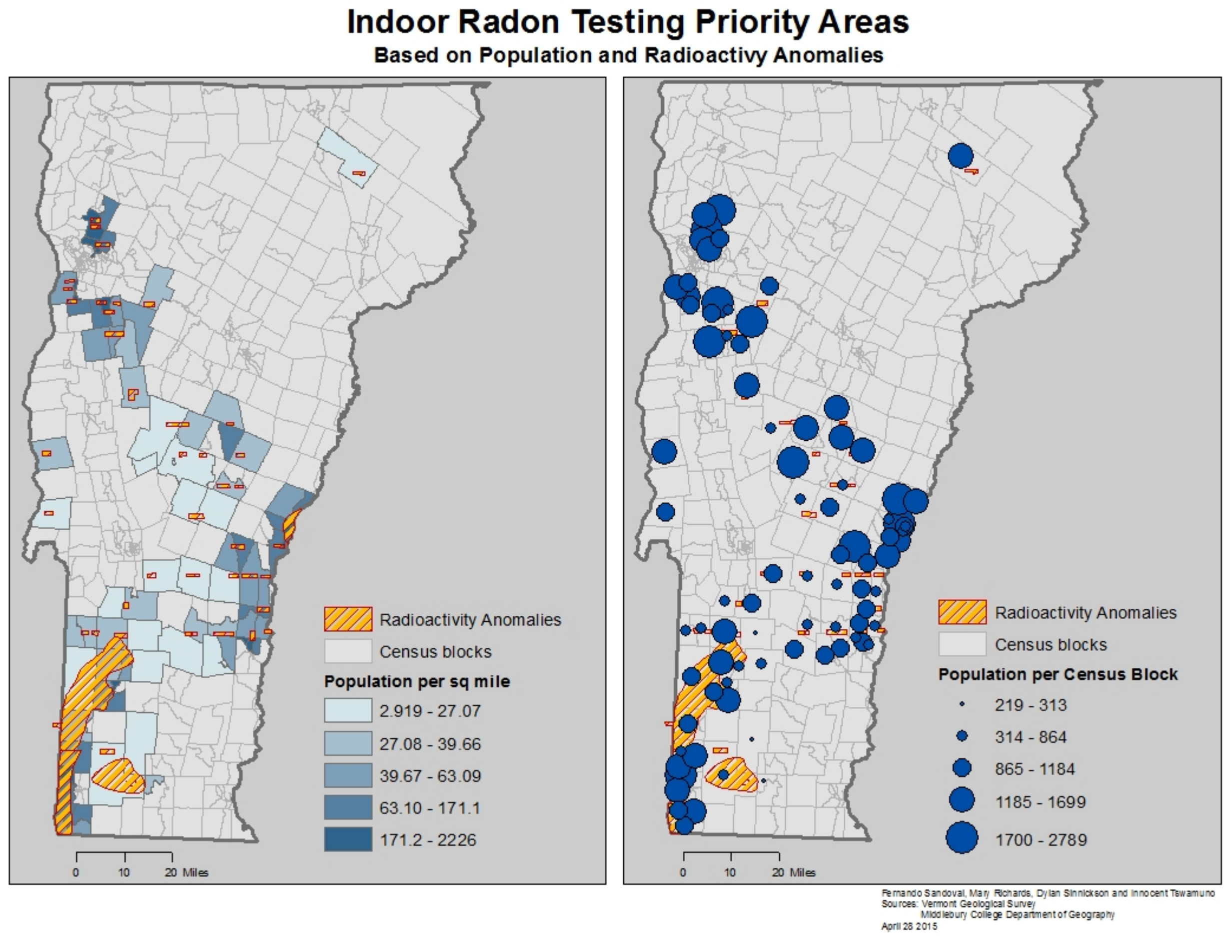
Title: Vermont Ground-Based NURE Survey Map
Authors: Mary Richards, Kevin Wood
Date: April 13, 2015
Scale: Vermont (1:1,120,461)

Description:
This map features the uranium-rich zones as delineated by the ground-based NURE survey overlaid onto a map of Vermont population density. This revealed that the uranium-rich zones are in low-population areas. Only three home radon tests fell within the uranium-rich zones and all recorded levels below 2 pCi/L; therefore, substantive conclusions
GIS files:

- VT_proj_join.shp (Vermont population data per census block)
  - Middlebury Department of Geography
- Nureground.shp
  - Source: Vermont Geological Survey (VGS)
- RadonAirTest9413_GeocodedMatched_Sept2013_ResultsOnlyShareVersion
  - Source: Vermont Department of Health (VDH)

Lineage

3. Obtained tests results within Nureground.shp polygons using INTERSECT (Analysis)
4. Obtained tests results outside Nureground.shp polygons using ERASE (Analysis)



Title: Indoor Radon Testing Priority Areas
Authors: Fernando Sandoval, Mary Richards, Dylan Sinnickson and Innocent Tswamuno
Date: April 28, 2015
Scale: Vermont (1:1,250,000)

GIS files:

- VT_proj_join.shp (Vermont population data per census block)
  - Middlebury Department of Geography
- vt _nure_stream.shp
  - Source: Vermont Geological Survey (VGS)
- projected_preferred_anomaly.shp (digitized polygons based on data from the NURE airborne radioactivity survey)
  - Source: Vermont Geological Survey (VGS)
- projected_secondary_anomalies.shp (digitized polygons based on data from the NURE airborne radioactivity survey)\
  - Source: Vermont Geological Survey (VGS)

Lineage

1. Merged vt _nure_stream.shp, projected_preferred_anomaly.shp and projected_secondary_anomalies.shp into a single polygone shapefile

2. Intersected output from step **1** with the VT census data to obtain only the census blocks that overlapped with polygons on step **1**.
3. Desplayed population data from step **2** as density (graduated color) and as total (graduated symbol).

Appendix B: Cost-Benefit Model Results

Appendix B1. Summary of cost and benefit for mitigating different levels of radon in a private home, for different discount rates.

		Low radon reduction (1.7 pCi/L)				Moderate radon reduction (9.4 pCi/L)				High radon reduction (36.7 pCi/L)			
Discount rate (%)		Total cost	Cost per pCi/L reduced	Total Benefit	Benefit per pCi/L reduced	Total cost	Cost per pCi/L reduced	Total Benefit	Benefit per pCi/L reduced	Total cost	Cost per pCi/L reduced	Total Benefit	Benefit per pCi/L reduced
Low discount rate	0.03	4,632	2,725	21,301	12,530	4,632	493	117,780	12,530	4,632	126	459,843	12,530
Moderate discount rate	1.48	3,977	2,339	13,064	7,685	3,977	423	72,236	7,685	3,977	108	282,027	7,685
High discount rate	5.00	3,073	1,807	4,116	2,421	3,073	327	22,758	2,421	3,073	84	88,852	2,421

Appendix B2. Summary of cost and benefit for mitigating different levels of radon in a typical school, for different installation costs.

		Low radon reduction (1.7 pCi/L)				Moderate radon reduction (9.4 pCi/L)				High radon reduction (36.7 pCi/L)			
Cost of abatement ($)		Total cost	Cost per pCi/L reduced	Total Benefit	Benefit per pCi/L reduced	Total cost	Cost per pCi/L reduced	Total Benefit	Benefit per pCi/L reduced	Total cost	Cost per pCi/L reduced	Total Benefit	Benefit per pCi/L reduced
low cost ($4,000)	4,000	9,595	5,644	91,349	53,734	9,595	1,021	505,104	53,734	9,595	261	1,972,055	53,734
medium cost ($39,500)	39,500	45,095	26,527	91,349	53,734	45,095	4,797	505,104	53,734	45,095	1,229	1,972,055	53,734
high cost ($75,000)	75,000	80,595	47,409	91,349	53,734	80,595	8,574	505,104	53,734	80,595	2,196	1,972,055	53,734

Appendix C: Draft Narrative

Radon: A Health Hazard That Must be Mitigated in Vermont

There may be a killer lurking in your home, silent and inconspicuous, but possibly deadly. Every year, about fifty Vermonters, many of whom have never smoked, lose their lives to lung cancer attributable to a colorless, odorless gas called radon. Annually killing 21,000 Americans, it is the second most prominent overall cause, as well as the leading environmental cause, of lung cancer related deaths.

Radon is a naturally occurring contaminant that occurs at low levels outdoors, but can lethally accumulate indoors by seeping in through cracks and other openings in buildings. Through radioactive decay, the gas produces alpha particles that can inflict genomic harm on the cells lining the lung and result in lung cancer.

Vermonter A of Washington County's East Barre suffered a deep personal loss due to radon. In the February of 2012, doctors diagnosed her 74-year-old mother, Vermonter B, who had been extremely ill for months, with terminal stage 4 lung cancer that had metastasized to her lymph nodes, bones, and brain. After over two years of fighting the disease, she passed away last June.

According to her daughter, Vermonter B was a simple woman who had grown up on a farm in Morgan, Orleans County. She enjoyed gardening, and fed her family of eight entirely off the produce she grew. She had a soft spot for animals, and cared for dozens of stray cats and dogs who came to her door throughout the years. "She loved her family more than she loved life," Vermonter A remarked.

"My mother had smoker's lung cancer, small cell carcinoma, and it's hard to believe it was from a few years of smoking when she was in her early 20's," she said. "Doctors also told her that her lung cancer had been brewing for 10 to 12 years prior to her first symptoms, and was, in the opinion of most of her doctors, a result of radon and having previously been a smoker."

Based on her doctors' recommendation, Vermonter B conducted two tests to check radon levels in her home: one in the basement, where Kathy's childhood bedroom had been, and the other by Vermonter B's recliner in the living room, where Vermonter B had slept beginning a couple years prior to her illness because lying down caused her discomfort. The results that came back were the highest that had ever been recorded in the state of Vermont.

"It is tragic to me what has happened to our family, and what seems to be [the] needless loss of our mother," Vermonter A said. 'I think this could have been prevented if more radon awareness had been available much, much earlier, like decades earlier."

She recalls that her little sister had brought home a kit to test their house with after learning about radon back in 1997. Her parents, however, thought it was a foolish waste of time. They left it unopened on the dining room table, and discarded it after a few weeks. Vermonter A had also encouraged her family members to test at least seven years ago, when she decided to test her own home, but most of them were unreceptive to her suggestion.

"They were ignorant about radon," she said. "My mother was not well educated…and was very gullible…thinking that if you don't know about something, it won't hurt you."

She feels that public awareness of the hazard radon poses is generally poor. “Even some of my mother's doctors, about 50% of them, said there is no connection between radon and lung cancer,” she said.

Vermonter A maintains that, in addition to increased awareness, state legislation on radon is necessary to decrease the health consequences of radon in Vermont. “I believe it's mandatory when purchasing a home in Vermont, that banks’ lending insist that a quick radon test be done, with results being available in I think a couple of days,” she said. “It might even be a good idea to have every home in the state that has not been tested, [be] sent a test kit, with the importance of it and directions on how to run it [enclosed].”

Vermonter A’s oldest daughter, who is expecting her first child–Vermonter A’s first grandchild–this June, currently lives in Vermonter B’s house. The home now has a radon abatement system, and her daughter runs tests every few years and adjusts the remediation system accordingly.

As Vermonter B’s loss has reminded her family, even in the absence of state laws requiring action against radon, such diligent testing and mitigation at the individual household level is vital to reducing the risk of radon-induced lung cancer for current and future generations.

Appendix D: Radon Rebel Materials

Simple, promotional flyer requested by Rob Bliss, Asst. Superintendent of the Rutland County school district to be distributed to educators and activities to be used in the classroom

RADON REBELS

A science and society education plan focused
on radon and designed for middle-schoolers

Who: Your Middle School students taught by volunteer High School students

What: Radon is a poisonous gas present homes, and is the second-leading cause of lung cancer with long-term exposure. Few people recognize this health risk, but testing and mitigation mechanisms are available to the public through the Vermont Department of Health. 1 in every 8 Vermont homes has dangerous levels of Radon, and our mission is to raise awareness of this natural contaminant to your students in a fun and engaging way, with the intention of garnering parental attention and radon intervention.

When: Program times are dependent on your schedule and the student leaders' schedules. Possible times are during the school day or as an afterschool program.

Where: Your classroom (or anywhere else you'd like to have it!)

Why: This program is designed to be a service-learning project for high school students. By working with them, you can help to increase student understanding of radon while also helping high school students make a contribution to the local community.

How: The lesson plan has been developed and is ready for adopting as-is or for adapting to specific goals. Education materials can be provided beforehand upon request. If interested, please contact Chloe Horton or Linda Waller for more information.

Chloe Horton: chorton@middlebury.edu
Linda Waller: lwaller@middlebury.edu

INVESTIGATION 1 What do people know about radon?

Levels of Radon in Jersey Town Exceed Limits

An Entire Neighborhood Affected by Problem

Unsafe levels of the radioactive gas radon have been found in 45 homes in and around a village in rural western New Jersey, including one home with the highest level yet detected in a building in the state.

The measure in the house was 250 times the federal Environmental Protection Agency's recommended indoor guideline for radon, which is known to cause lung cancer in miners.

Radon is a naturally occurring radioactive gas formed by the radioactive decay of uranium and radium and enters homes through small cracks and openings from the soil under and around the house.

Federal officials warn that the radon threat is greater than had been first recognized and may cause 14,000 lung cancer deaths a year. They urge that all houses and apartments up to the second floor be tested for this colorless, odorless gas.

Many of the homeowners in this rural community indicated that steps were already being taken to fix the radon problem in their homes.

INVESTIGATION 1 What do people know about radon?

____
Name

Think about radon

From the newspaper article, write down five words that are associated with radon.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

Define each of the words above.

6. WORD: ________________ DEFINE IT ____________________
____
7. WORD: ________________ DEFINE IT ____________________
____
8. WORD: ________________ DEFINE IT ____________________
____
9. WORD: ________________ DEFINE IT ____________________
____
10. WORD: ________________ DEFINE IT ____________________
____

INVESTIGATION 1 What do people know about radon?

____
Name

Find some people

Who? Interview 5 friendly people in your community
(Ask your family to help you identify these people)

What? Ask your participants the questions on the next page

Where? At home, at the park, in the neighborhood, over the phone

Why? To learn how to collect data

IDENTIFY 5 PEOPLE WHO COULD COMPLETE THIS SURVEY

Name	**Relationship**
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________

DO'S & DON'TS

1. Do thank the person when you are finished.
2. Do speak loudly and clearly.
3. Do allow time for the person to respond to each question.
4. Don't conduct the survey with a stranger.
5. Don't give up!

Handout #4

INVESTIGATION 1 What do people know about radon?

Conduct a survey

____
Friendly Person to Interview

Directions: Please answer the questions below. Begin each question with "Do you think..." and circle either YES or NO.

DO YOU THINK
1. Radon is a health hazard? YES NO

DO YOU THINK
2. Your home should be tested for radon? YES NO

DO YOU THINK
3. There is natural radiation around us all the time? YES NO

DO YOU THINK
4. Radon can be located in a home by its smell? YES NO

DO YOU THINK
5. Radon can be easily removed from a person's home? YES NO

DO YOU THINK
6. Some radon enters homes through cracks in the ceiling? YES NO

DO YOU THINK
7. Everybody should know the radon level in their homes? YES NO

DO YOU THINK
8. Some radon comes from some building materials? YES NO

INVESTIGATION 1 What do people know about radon?

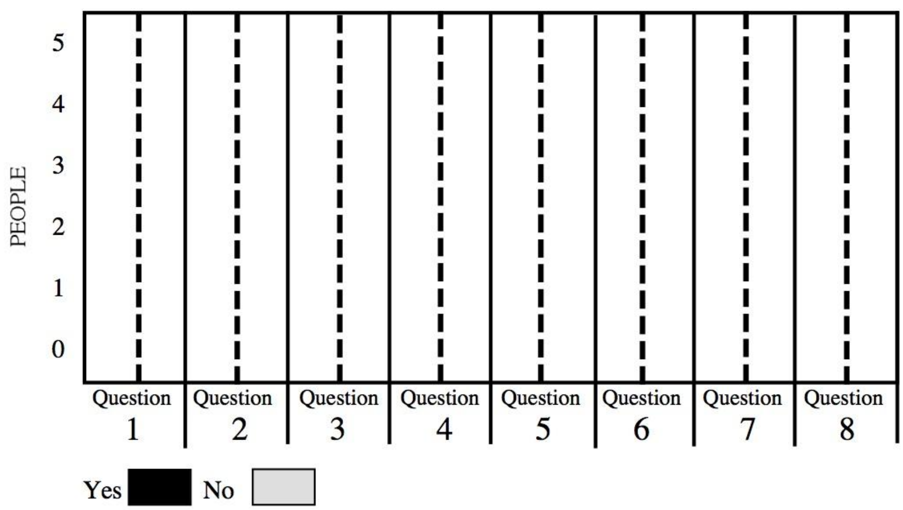
Tally some data

Name ____________________

	YES	NO
QUESTION 1		
QUESTION 2		
QUESTION 3		
QUESTION 4		
QUESTION 5		
QUESTION 6		
QUESTION 7		
QUESTION 8		

MARK DOWN THE TOTAL NUMBER OF YES's AND NO's FOR EACH QUESTION.

FILL OUT THE BAR GRAPH



INVESTIGATION 1 What do people know about radon?

____
Name

Think it over

1. Which survey questions got the most "Yes" answers?

   ____

   What does that mean to you?

   ____

2. Which survey questions got the most "No" answers?

   ____

3. Does the survey show that people know a lot about radon?

   ____

   How much do you know about radon?

   ____

4. How did your own answers to the survey compare to the group study?

   ____

   ____

INVESTIGATION 1 What do people know about radon?

Conduct a survey

____
Friendly Person to Interview

Directions: Please answer the questions below. Begin each question with "Do you think..." and circle either YES or NO.

DO YOU THINK . . .
1. ____ **?** YES NO

DO YOU THINK . . .
2. ____ **?** YES NO

DO YOU THINK . . .
3. ____ **?** YES NO

DO YOU THINK . . .
4. ____ **?** YES NO

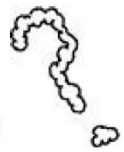
DO YOU THINK . . .
5. ____ **?** YES NO

DO YOU THINK . . .
6. ____ **?** YES NO

DO YOU THINK . . .
7. ____ **?** YES NO

DO YOU THINK . . .
8. ____ **?** YES NO

INVESTIGATION 1 What do people know about radon?



Name

Ask some questions

Write down questions that you would like answered about radon.

Question #1

Question #2

Question #3

Question #4

Question #5

INVESTIGATION 7 How does radon get in?

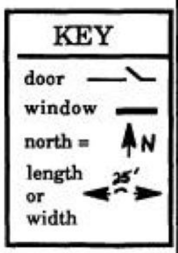
Name

Sizing up the house

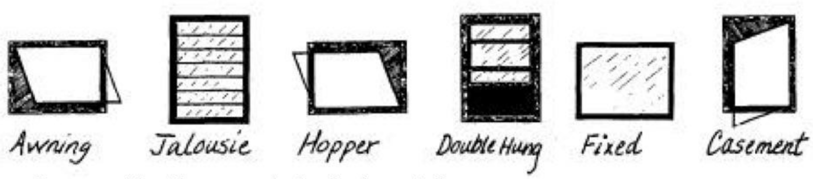
In order to do a radon investigation of your home, important information about room size and design is needed. You will need a tape measure or ruler.

1. In the space below, sketch the general shape of the first floor of your house if you were looking down from the top.

2. Using the key, show the location of doors and windows on your sketch.



3. In the sketch above, number every window in the room.
4. Circle the window type that is most like the windows in your house.



5. Put a star * beside any cracked or broken windows.

INVESTIGATION 7 How does radon get in?

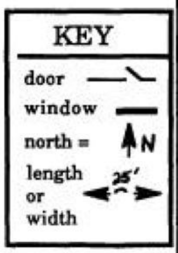
Name ____________________

Sizing up the house

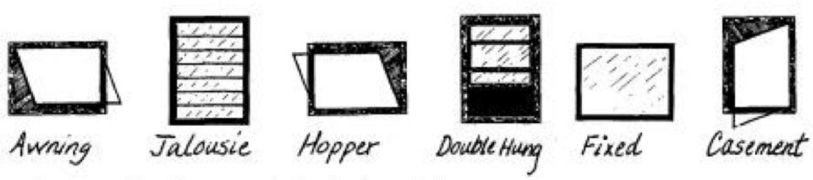
In order to do a radon investigation of your home, important information about room size and design is needed. You will need a tape measure or ruler.

1. In the space below, sketch the general shape of the first floor of your house if you were looking down from the top.

2. Using the key, show the location of doors and windows on your sketch.



3. In the sketch above, number every window in the room.
4. Circle the window type that is most like the windows in your house.



5. Put a star * beside any cracked or broken windows.

INVESTIGATION 7 How does radon get in?

____
Name

Do some calculations

1. Do the following calculations:

   A. Total number of openings such as doors, windows, and cracks (Add one square cm for each) __________

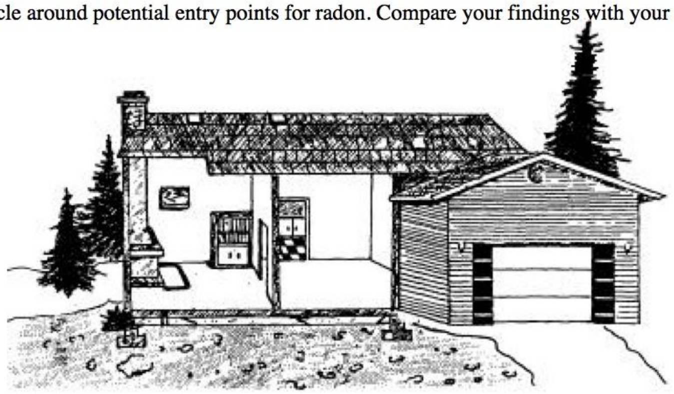
   B. Number of fans (Add three square cm for each) __________

   C. Number of fireplaces/woodstoves (Add six square cm for each) __________

   D. Sum of A, B, and C __________

Inspect this house

2. Draw a circle around potential entry points for radon. Compare your findings with your neighbor.



Did you know?

Radon can get into a building several ways. One way is through a crack or joint in the floor. Another way is through a crack in a basement wall or near the ground. A third way is through a drain in the floor. Sometimes it can get in where pipes enter a house through the floor.

Note: Remember that radon is to a crack like a penny is to a baseball stadium. It doesn't need much room to get inside!

INVESTIGATION 7 How does radon get in?

Name

Try these questions

1. What are the three most important routes of radon entry into your home?

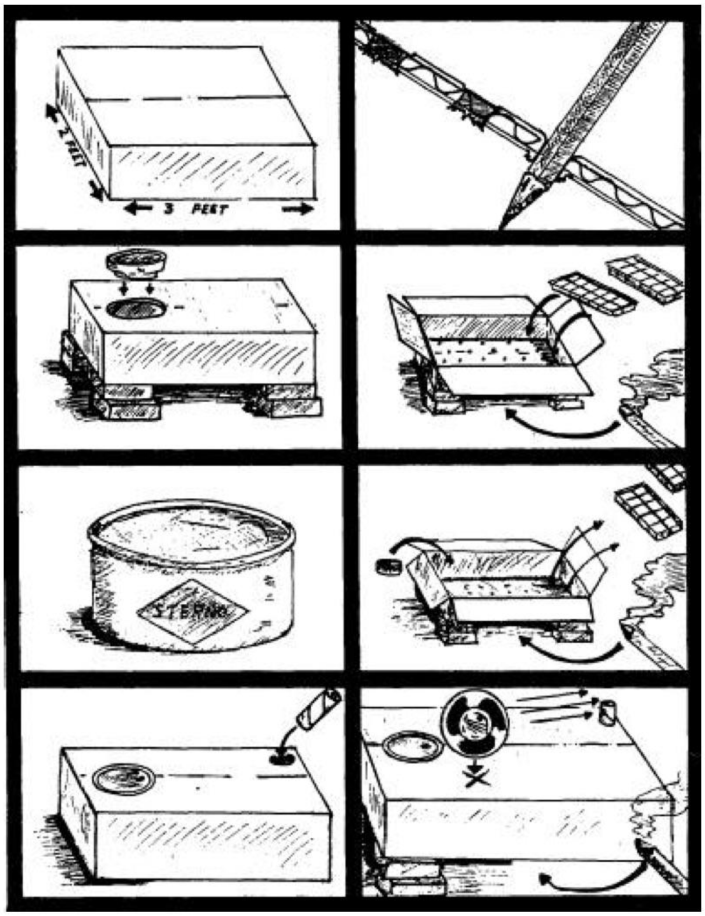
2. Do you think it is better to live in a well ventilated home versus an air tight home?

   EXPLAIN:

INVESTIGATION 9 Can the radon problem be fixed?

Name

Follow these instructions



Step 1

Step 2

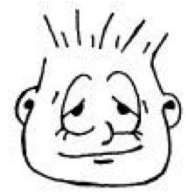
Step 3

Step 4

INVESTIGATION 9	Can the radon problem be fixed?

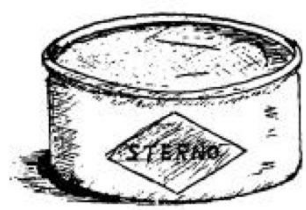
Name

Air flow and radon



1. Place two trays of ice cubes in the box.
2. Light the punk.
3. Place punk underneath box.

What happened?



1. Place the Sterno® in the box.
2. Light the punk.
3. Place punk underneath box.

What happened?

INVESTIGATION 9 Can the radon problem be fixed?

1. Cut a hole in the top of the box
2. Insert an empty toilet paper roll.
3. Turn on a fan on top of the box.
4. Light the punk.
5. Place punk underneath box.

What happened?

____

____

____

Think it over

1. Under what conditions was the smoke alarm activated? ____________________

____

2. Why do you think this happened? ____________________

____

____

3. Radon is an odorless, colorless gas. It seeps into your home just like the smoke in the smoke experiment. Did more smoke enter the cardboard box with the ice cubes, the Sterno® or the fan?

____

4. Why do you think this happened? ____________________

____

INVESTIGATION 9 Can the radon problem be fixed?

____
Name

Design a solution

1. What modifications did you make to reduce or remove the smoke from entering your card board house?

____

____

2. What modifications did you make to remove the smoke that was already in your cardboard home?

____

____

Did you know?

There are different ways to mitigate or fix the radon problem in a home. The first thing that has to be done is seal any cracks or holes in the walls and floors to keep the radon from entering the house.

If the radon problem in a house is not too bad, one simple way to get it out is to just open the doors and windows of the house and let the wind blow the radon out the windows. In cold weather this could let the heat out. If you don't have screens on the windows, bugs or wild animals, like squirrels can get in. There may be other possible problems with just leaving windows open. Can you list them?

Appendix E: Policy Supplements

E.1: Calculation of VT Deaths

David Grass, VDH: I applied the national % of lung cancer deaths attributable to radon, ("EPA estimates that out of a total of 157,400 lung cancer deaths nationally in 1995, 21,100 (13.4%) were radon related"[1],) to lung and bronchus cancer mortality rate from the VT cancer registry (382/year VT deaths for 2006-2010) (EPA, 2003). And I did the same to get the number of the radon-attributable deaths that would occur among ever smokers (ES) ("It is estimated that 86% of the radon-related lung cancer deaths were in ES, compared to 93% for all lung cancer deaths."[1], or 43 out of 50). I got 50 rather than 51 radon attributable deaths, because I didn't use the lung cancer total from 1995, but a different year with a slightly higher total lung cancer mortality figure, so the rate I used was closer to 13% rather than 13.4%. It's worth noting that the uncertainty range given around the figure of 21,000 annual U.S. radon-induced lung cancer deaths is large: 8,000 to 45,000. So uncertainty around the 50 radon deaths per/year figure for Vermont is similarly large.

E.2: Health Cost Tradeoffs

Since the average age of lung cancer incidence is 70, the cost of this treatment is borne primarily by the State through programs such as Medicare and Medicaid. Thus, radon mitigation will yield monetary benefits through health care cost reductions (VDH, 2010). The average annual cost of lung cancer treatment in 2000 was $56,385 per patient (Cipriano, et al. 2011). When adjusted for inflation, the annual cost in 2015 is $78,668 per patient (USDL, 2015). According to the Vermont Department of Health figures, approximately 58 people are treated for lung cancer attributable to radon exposure annually; by avoiding this treatment $4,562,744 will be saved annually to the overall healthcare system (VDH, 2010).

The monthly costs for lung cancer treatment in 2000 ranged from $2,687 to $9,360; this is representative of patients receiving no active treatment to patients receiving chemo-radiotherapy (Cipriano, et al. 2011). Due to the aggressive nature of lung cancer and the average stage of diagnosis, the normal distribution for treatment costs are skewed heavily to the right; meaning there is a significant chance that the average costs listed above are an underestimate. (VDH, 2010) In addition, using the average mortality rate yields a cost value that is concrete, but it is not representative of all individuals being *currently* treated for radon-induced lung cancer. This is to say that the number of people generating a cost to the system is higher than 50.

E.3: VPIRG past education and coalition strategies can be summarized as follows:

- Radon awareness week in October; Press Conference in November
- Promotion through radio PSA, news release, talk shows, and other media
- VPIRG newsletters to ~20,000 households (10% of the population)
- Postings at grocery stores, natural food stores, and other commercial outlets
- Cooperation with Utilities: Radon information in customer bills
    - Burlington Electric Department agreed to include info on radon and testing methods to 17,000 customers in Feb '94

        - Negotiated with Washington Electric Cooperative - serves 12,000 customers. Results unknown
    - Outreach to large companies for employee training
    - Encourage science classes in schools to test - integrate into curriculum
        - Exploring collaborative opportunities with other indoor air quality issues

While there was a flurry of activity during this period, the efficacy in terms of directly driving testing and mitigation decisions are unclear. VPIRG reported that the media campaign (radio, TV, print) generated approximately 100 callers interested in further information in two weeks. Radon awareness tables at commercial outlets in Chittenden County prompted the distribution of 200 short-term test kits. As of the Mid-Term Report, VPIRG accomplished all goals to speak to two groups per month, offer two public information tables per month, and to distribute 100 radon test kits per month. However, this report and further follow up did not include any information regarding costs or efficacy of the other strategic measures outlined above.

We propose that the state of Vermont preserve the VDH radon program budget and their role as the lead organization for radon education. We recommend funding be used to continue the provision of free test kits, revitalize partnerships, support community service programs, and prioritize all outreach efforts according to risk criteria and population density. Adoption of this plan can be expected to boost home testing rates, particularly in at-risk geographies, without imposing an increased cost to the state given the current macro policy environment.

E.4: Current Education and Outreach Initiatives in Vermont

In the past year, VDH distributed 1,603 kits to residents - a nearly 20% increase from the previous year. However, VDH is still plagued by a relatively low return rate, as only 58% of test kits were subsequently submitted for laboratory testing.

The VDH work plan for 2015 is focused primarily on three priority areas: increase radon testing, increasing mitigation and reporting, and education and outreach. The overarching goal is to distribute 2,000 long term test kits. To achieve this goal, the test kit program will be promoted through partnerships with town health officers, home and trade shows, and pediatricians encouraging patient testing. The media campaign will target print media advertisements in areas with high test results as well as low testing coverage.

Private interest seems to be at a minimum at this time. VPIRG no longer lists radon as an issue and confirmed that they don’t currently provide any support for radon programs. ALA support is primarily at a national level and has minimal involvement with VDH currently.

E.5: Radon Resistant New Construction

<u>Techniques</u>

- **Passive Sub-Slab Depressurization System** consists of:
    - Gravel: a loose layer of gravel allows soil gases to circulate freely, due to its porosity.
    - Plastic Sheeting/Vapor Retarder: prevents seeping.
    - Vent Pipe: pipes soil gases through the house to vent outside the house.

- Sealing/Caulking: seals all cracks and entry points to prevent intrusion.
- Junction Box: powers the ventilation fan for "future activation of the system."

- **Active Sub-Slab Depressurization System** consists of the features listed above, in addition to a radon vent fan, which "actively draws radon from the soil to the stack." (ELI 2012:26).

According to the National Association of Home Buyers, there have been 1.5 million new homes built with RRNC since 1990 (NAHB). The ELI's 2012 report cited 2008 EPA data: "of more than 1.5 million single-family homes built in Zone 1 high radon potential areas from 2001 to 2005, only about 18 percent were built with radon-resistant new construction features" (ELI, 2012, p. 25). The overall rate across risk Zones was seven percent.

"Seven states [Illinois, Maryland, Michigan, Minnesota, New Jersey, Oregon, and Washington] in the U.S. require the installation of passive radon control systems as part of their residential building codes" (ELI, 2012, p. 35). The majority (5/7) of these states have either adopted or amended the radon control standard (an optional appendix) of the International Residential Code (IRC). Some of these states have designated RRNC mandates for only those areas within the EPA's Zone 1 of high-risk; the rest mandate statewide RRNC. Maine also includes RRNC in its statewide building code it established in 2008, but it leaves the decision to incorporate features of RRNC to the discretion of the homeowner or builder (ELI, 2012, p. 26).

E.6: Certification Program

Currently 13 states have policies that establish a state certification program: Florida, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Nebraska, New Jersey, Ohio, Pennsylvania, Rhode Island, and West Virginia.

E.7: Radon Deaths in Vermont Schools

Of the 65 schools that VDH has tested so far, 7 (10.8%) have tested above the EPA action level of 4 pCi/L (no data is available for the schools that tested below the action level). Generalizing this to all schools, it was estimated that 9102 Vermont students (10.8% of the 84,519 students currently enrolled) are exposed to elevated radon levels in school. No specific testing results are available for elevated schools, so the levels are assumed to be 4 pCi/L. This was used to calculate an individual's lifetime risk of radon-induced lung cancer death using the dose-response curve presented in Chapter 2 and multiplied by the number of students to estimate how many deaths one could expect in the next 100 years (66). The same procedure was performed to estimate the number of deaths expected if all of these schools' radon levels were reduced to 2 pCi/L (33), and the difference between these two numbers was calculated to estimate the number of lives that would be saved in this scenario. Following Petersen and Larsen (2006) the timeframe given is 100 years since no schoolchildren will be exposed a lifetime of exposure in school, since eventually they will graduate. However, assuming constant occupation of the school buildings, over the next 100 years (a convenient number to model a human life), the equivalent of 84,519 lifetime exposures will occur in schools, meaning we can estimate the number of statistical lives saved even without a dose-response curve that takes into account duration of exposure.

This figures is likely to be an underestimate for the following reasons:
1) It does not take into account teachers, staff, or other adults working in schools;

2) It assumes that schools that tested above the EPA threshold have exactly levels at exactly 4 pCi/L, when in reality all of them likely have levels above 4 pCi/L, to some degree;
3) It uses the dose-response curve for "never-smokers." While smoking levels are certainly lower among schoolchildren than among the general population, some schoolchildren are exposed to second-hand smoke at home and therefore are at greater risk for radon-induced lung cancer than never-smokers;
4) It assumes constant enrollment in Vermont schools, when in reality enrollment will certainly increase.

E.8: Radon testing protocols in prisons

A variety of organizations, including EPA and the American Association of Radon Scientists and Technologists (AARST), recommend that all frequently-occupied rooms in large buildings be tested individually (EPA, 1993b; Melton, 2014). However, due to security concerns and logistical reasons (the difficulty of keeping a test kit in one place in each cell for 3 months), this protocol would not be feasible in most correctional facilities. Thus, we hope that the Department of Corrections will work with the New England chapter of the American Association of Radon Scientists and Technologists to develop a testing protocol that will balance the need for a representative sample of radon concentrations throughout prison buildings with the unique security and logistical concerns found in correctional facilities.

E.9 Other States' Policies in Rental/Subsidized Housing Properties:

● Illinois Compiled Statutes Ch. 420 46/1-25 requires landlords of residential units below the third story to notify current and prospective tenants of any radon hazard revealed by landlord's testing of the property, unless landlord mitigates the property and eliminates the hazard. Requires landlord to disclose to prospective tenants any radon hazard revealed by current tenants' testing, unless landlord's testing demonstrates that a hazard does not exist.
● Maine Revised Statutes, tit. 14, 6030-D requires residential landlords to have the air in their buildings tested for radon. Requires re-testing every 10 years when requested by a tenant, unless a radon mitigation system has been installed. Requires the landlord to provide a written radon notice to tenants and prospective tenants, including information on the risks of radon; the date and results of the most recent radon test (including tests conducted by a tenant showing elevated radon levels); the tenants right to conduct a test; and any completed mitigation. Fine of $250 per violation. Requires reporting of test results to the state.
● New Hampshire Revised Statute 125:9 requires the Department of Health and Human Services to investigate complaints of poor indoor air quality and to conduct inspections of buildings and dwellings, upon request, for the presence of radon or other health hazards in indoor air.

E.10 Other State Policies in Private Businesses:

● **New Hampshire** Revised Statutes 125:9 requires the Department of Health and Human Services to investigate complaints of poor indoor air quality and to conduct inspections of buildings and dwellings, upon request, for the presence of radon or other health hazards in indoor air.
● **Oregon** Revised Statutes 433.502-526 authorizes the Department of Human Services to conduct Indoor Air Quality (IAQ) field investigations and establish IAQ standards. Authorizes the Department to establish a public recognition program for office workplaces, buildings, and public areas that consistently meet the IAQ requirements set forth in state law.
● **Rhode Island** General Laws 23-61-1 et seq. authorizes the Department of Health to require that owners of "public or high priority buildings" test for radon.